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CONTENTS

PAGE

Cancer of the Lung and Nose in Nickel Workers. RICHARD DOLL 217

Some Observations on the Incidence of Respiratory Cancer in Nickel Workers. J. GWYNNE MORGAN 224

The Pathology of the Lungs in Five Nickel Workers. W. JONES WILLIAMS 235

Chronic Chloroform Intoxication. P. J. R. CHALLEN, D. E. HICKISH, and JOAN BEDFORD .. 243

Counting Errors due to Overlapping Particles in Thermal Precipitator Samples. S. A. ROACH 250

Respiratory Function of Witwatersrand Gold-miners. SAUL ZWI and MARGARET R. BECKLAKE 258

A Statistical Study of Coal-mining Accidents. F. D. K. LIDDELL and JOAN MAY 262

Aseptic Necrosis of Bone in Caisson Disease. JOHN D. THOMSON and ANDREW B. YOUNG 270

Some Notes on the Effects of Excessive Noise on the Hearing of a Group of Workers. G. F. KEATINGE and S. LANER 273

An Investigation of Some Health Hazards in an Inert-gas Tungsten-arc Welding-shop. P. J. R. CHALLEN, D. E. HICKISH, and JOAN BEDFORD 276

The Estimation of Gaseous Acid in Domestic Premises. J. J. PHAIR, R. J. SHEPHARD, G. C. R. CAREY, and M. L. THOMSON 283

Quarry Bank Mill: I. The Story of the Mill. ROBERT MURRAY 293

Book Reviews 299

Index to Volume 15 305

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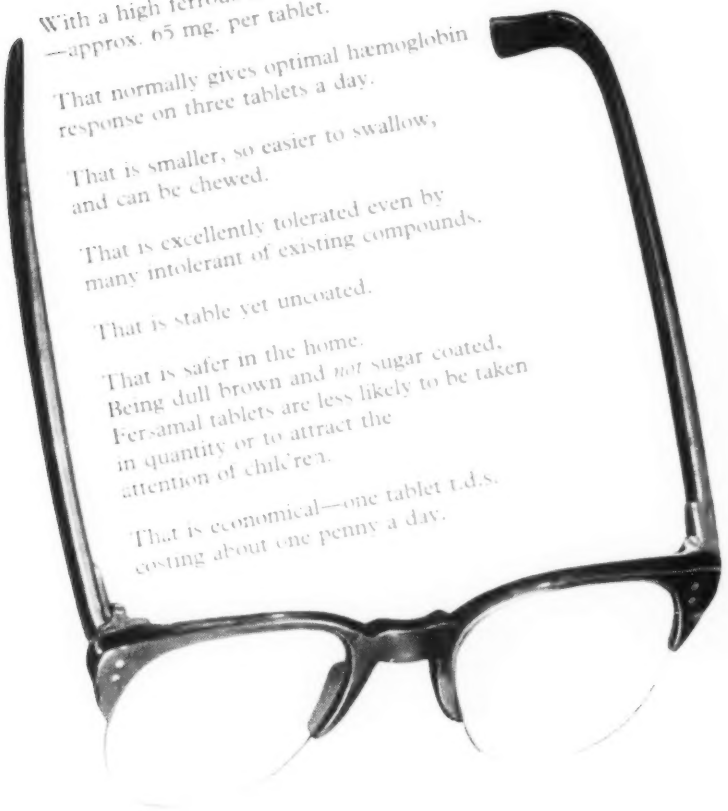

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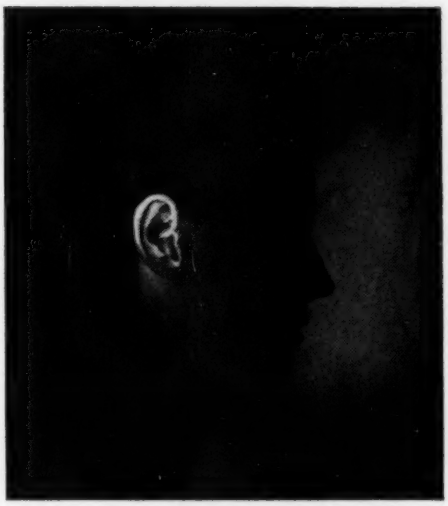

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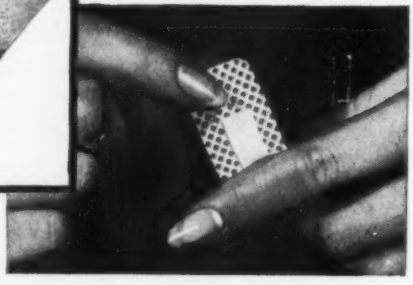

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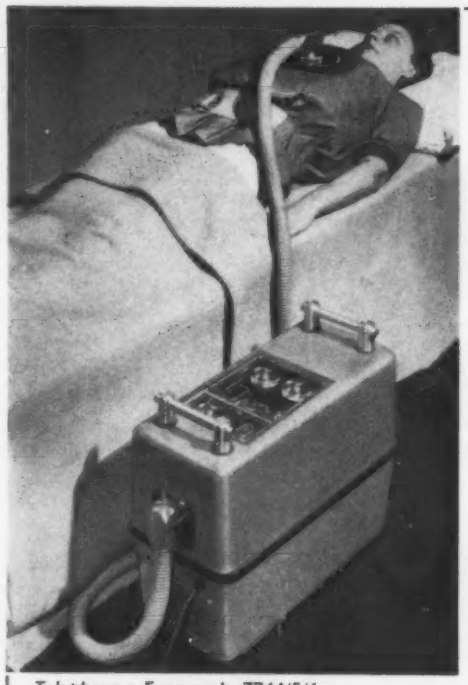

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Brit. J. industr. Med., 1958, **15**, 217.

CANCER OF THE LUNG AND NOSE IN NICKEL WORKERS

BY

RICHARD DOLL

From the Statistical Research Unit, Medical Research Council, London

(RECEIVED FOR PUBLICATION FEBRUARY 4, 1958)

In 1949 the Minister of Pensions and National Insurance of Great Britain prescribed cancer of the lung and cancer of the nose as industrial diseases, when they occurred among certain classes of workers engaged in the refining of nickel. The published epidemiological evidence regarding the hazard is, however, scanty. It consists only of a series of case reports (Amor, 1939; Løken, 1950) and a statement of the total number of cases which occurred between 1923 and 1950 and were reported to the Ministry (Chief Inspector of Factories, 1952). The present investigation was, therefore, undertaken to obtain evidence relating to (1) the magnitude of the risk, and (2) the belief that the risk had been eliminated from the refinery concerned between 1920 and 1924.

The data for the investigation were obtained from the records of death held by the medical officers of health of the districts in which the workers at the refinery lived. These records included copies of the death certificates of all persons dying in the districts and also of the certificates of persons resident in the districts, who had died elsewhere. Since the majority of the workers live in the Pontardawe Rural District of the County of Glamorganshire and a few others live in the County Borough of Swansea and in two other neighbouring districts, it was possible to obtain information about the causes of death of nearly all—if not of all—the workers who died during employment at the refinery and of a large proportion of the retired workers who had worked at the refinery when they had last been employed. These data can be compared with the national data for the different causes of death during the same period or with similar data for the same districts, but relating to men in other occupations. In the present study, it was thought better to use the other data from the same districts, when they were numerically adequate, as by this means it was possible to eliminate differences in the incidence of the two diseases due to non-industrial local factors.

The Data

Data for the 15,247 men over the age of 15 years who were resident in the four selected districts and who died in the period 1948-56 are shown in Table 1. The numbers of deaths are shown separately for three causes, five occupational groups, and 13 age groups. The causes have been classified as cancer of the lung, cancer of the nose, or " other causes " according to the diagnosis given on the death certificate. Where two or more causes were referred to the death has been classified to the underlying cause, in accordance with international usage—except in 10 instances in which a primary cancer of the lung was given as an associated disease, when the death was classified as if it had been attributable to the cancer. The numbers of cases in each occupational and age group in which the international usage was varied are shown in Table 1. The five occupational groups consist of nickel, steel, and colliery workers, men employed in certain " other selected occupations ", and those in all other occupations. The men in " other selected occupations " were employed at an oil refinery or were described as aluminium, copper, spelter or " patent fuel " workers; they were studied separately because it was thought possible that one or other of these industries might also carry a specific risk of lung cancer.

The death records for earlier periods were available in the offices of the medical officers of health for only two of the four areas studied; one of them was, however, the area in which the refinery is situated and in which the majority of the nickel workers resided. Data for these two areas for the period 1938-47 are shown in Table 2: the corresponding data for the period 1948-56 (included in Table 1) are also shown in Table 2 for comparison. The data are shown in the same way as in Table 1, save that, because of the smaller numbers, they are given in larger age groups.

TABLE 1

NUMBER OF DEATHS FROM CANCER OF LUNG AND OF NOSE AND OTHER CAUSES AMONG MEN RESIDENT IN FOUR LOCAL AUTHORITY AREAS IN SOUTH WALES (1948-1956) SUBDIVIDED BY AGE AND NATURE OF LAST EMPLOYMENT

Age at Death (years)	Number of Deaths among Men Employed in:																		
	Nickel Industry			Other Selected Occupations*			Steel Industry			Coal-mining			All Other Occupations			All Occupations			
	Cancer of Lung	Cancer of Nose	Other Causes	Cancer of Lung	Cancer of Nose	Other Causes	Cancer of Lung	Cancer of Nose	Other Causes	Cancer of Lung	Cancer of Nose	Other Causes	Cancer of Lung	Cancer of Nose	Other Causes	Cancer of Lung	Cancer of Nose	Other Causes	All Causes
15–	0	0	1	0	0	2	0	0	12	0	0	16	0	0	141	0	0	171	171
25–	0	0	4	0	0	23	0	0	15	0	0	47	5	0	214	5	0	299	304
35–	0	0	6	1	0	17	2	0	63	2	0	104	14	0	373	19	0	564	583
45–	1	0	3	6	0	34	10	1	64	4	0	99	40	0	365	61	1	565	627
50–	11	1	16	8	0	54	15†	0	105	13	0	158	68	0	510	115	1	844	960
55–	11	1	22	9	0	67	17†	0	158	8	0	201	87	5	778	132	6	1,226	1,364
60–	15	2	13	18	0	79	32	0	233	16†	0	336	106‡	0	1,041	187	2	1,702	1,891
65–	8	7	28	7	1	86	28†	0	318	10	1	399	94	0	1,328	147	9	2,159	2,315
70–	2	1	19	4	0	85	10	0	352	12‡	1	470	59‡	1	1,378	87	3	2,303	2,393
75–	0	1	21	1	0	78	5	0	361	6	0	463	23	0	1,314	35	1	2,237	2,273
80–	0	0	6	0	0	47	2	1	251	1	0	302	6	0	916	9	1	1,526	1,536
85 and over	0	0	0	0	0	33	0	1	119	0	0	133	1	0	525	1	1	810	812
Not stated	0	0	0	0	0	1	0	0	4	1	0	1	0	0	11	1	0	17	18
All ages: 15 and over	48	13	139	54	1	606	121	3	2,055	73	2	2,729	503	6	8,894	799	25	14,423	15,247

*Men employed in aluminium, copper, spelter, and " patent fuel " works and in oil refineries.
†Including one case (‡two cases) in which primary lung cancer was referred to as an associated condition and not as the direct cause of death.

Cancer of the Lung

From the data shown in Table 1 it is, of course, impossible to calculate death rates, since the numbers of men employed in the different occupations are not known. If, however, the experience of one of the occupational groups is used as a standard, it is possible to estimate the numbers of deaths expected to be due to lung cancer in the other groups. The most suitable group to use in this way is the group of men employed in " all other occupations ". The

TABLE 2

NUMBERS OF DEATHS FROM CANCER OF LUNG AND OF NOSE AND OTHER CAUSES AMONG MEN RESIDENT IN TWO LOCAL AUTHORITY AREAS IN SOUTH WALES (1938-47 AND 1948-56) SUBDIVIDED BY AGE AND NATURE OF LAST EMPLOYMENT

Period	Age at Death (years)	Number of Deaths among Men Employed in:																		
		Nickel Industry			Other Selected Occupations*			Steel Industry			Coal-mining			All Other Occupations			All Occupations			
		Cancer of Lung	Cancer of Nose	Other Causes	Cancer of Lung	Cancer of Nose	Other Causes	Cancer of Lung	Cancer of Nose	Other Causes	Cancer of Lung	Cancer of Nose	Other Causes	Cancer of Lung	Cancer of Nose	Other Causes	Cancer of Lung	Cancer of Nose	Other Causes	All Causes
1938 to 1947	15–	0	0	2	0	0	0	0	0	17	0	0	28	0	0	62	0	0	109	109
	25–	0	0	2	0	0	6	0	0	39	0	0	48	0	0	82	0	0	177	177
	35–	0	0	7	0	0	6	2	0	53	1	0	69	0	0	94	3	0	229	232
	45–	14	2	23	0	0	8	9	0	77	1	0	154	9	0	189	33	2	451	486
	55–	16	12	36	0	0	12	7	0	176	3	0	271	13	1	390	39	13	885	937
	65–	6	2	20	0	0	8	4†	1	241	2	0	311	5	1	455	17	4	1,035	1,056
	75 and over	0	0	2	0	0	5	0	0	201	1	1	190	2	0	428	3	1	826	830
	Not stated	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	1	1
	All ages 15 years and over	36	16	92	0	0	46	22	1	804	8	1	1,071	29	2	1,700	95	20	3,713	3,828
1948 to 1956	15–	0	0	0	0	0	1	0	0	3	0	0	4	0	0	28	0	0	36	36
	25–	0	0	2	0	0	2	0	0	3	0	0	14	1	0	43	1	0	64	65
	35–	0	0	4	0	0	2	1	0	21	1	0	47	2	0	78	4	0	152	156
	45–	9	1	12	3	0	17	10†	0	55	6	0	117	18	0	161	46	1	362	409
	55–	21	3	24	2	0	12	13	0	151	8†	0	220	30	1	353	74	4	760	838
	65–	9	8	37	0	0	21	18†	0	256	8‡	2	347	31†	0	533	66	10	1,194	1,270
	75 and over	0	1	18	0	0	3	3	1	308	0	0	334	6	0	589	9	2	1,252	1,263
	Not stated	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—
	All ages 15 years and over	39	13	97	5	0	58	45	1	797	23	2	1,083	88	1	1,785	200	17	3,820	4,037

*Men employed in aluminium, copper, spelter, and " patent fuel " works and in oil refineries.
†Including one case (‡two cases) in which primary lung cancer was referred to as an associated condition and not as the direct cause of death.

number of deaths is large and the types of occupation are numerous and varied; the total mortality of the group is, therefore, unlikely to have been influenced to any great extent by any single occupational factor. The number of deaths expected to be due to lung cancer in the other occupational groups may then be estimated by assuming that the ratio between the number due to lung cancer and the number due to " other causes ", that is, all causes, other than cancer of the lung or nose, should be the same, at each age, as in the standard group. For example, there were 87 deaths due to lung cancer and 778 deaths due to " other causes " among men aged 55-59 years employed in " all other occupations ". There were 22 deaths due to " other causes " among men of the same ages employed in the nickel industry and it is, therefore, estimated that the expected number of deaths from lung cancer among the nickel workers is $\frac{87}{778} \times 22$, *i.e.*, 2·46. The number actually observed was 11. The results obtained by calculating the expected numbers for each of the age groups studied and summing for all ages are shown in Table 3*. Among the nickel workers the number of lung cancer deaths observed was nearly five times the number expected. Among the steel workers and the workers in the group of " other selected occupations ", the observed numbers were close to, but slightly higher than, the expected numbers; among the colliery workers the observed number was substantially less.

TABLE 3

COMPARISON BETWEEN OBSERVED AND EXPECTED NUMBERS OF DEATHS FROM CANCER OF LUNG IN FOUR OCCUPATIONAL GROUPS

No. of Deaths	Nickel Workers	Men in Other Selected Occupations	Steel Workers	Colliery Workers
Expected from the experience of men in " all other occupations "	9·88	39·12	110·97	152·16
Observed	48	54	121	73
Observed as % of expected	486	138	109	48

In this investigation, which is essentially a study of proportional mortality, a number of alternative explanations of the results are possible. The proportion of lung cancer deaths among the standard population may be abnormally low, the number of deaths from " other causes " among the nickel workers may be abnormally few, or the deaths from lung cancer may be excessive. The first explanation can be dismissed, since the proportion of lung cancer deaths in the standard population was very close to that which would have been expected on the basis of the mortality data for the whole country. From the national data it can be calculated that 493 deaths from lung cancer would be expected to have accompanied the 8,894 deaths from causes other than cancer of the lung and nose which occurred at the ages shown in Table 1; in fact, the number of lung cancer cases was 503 and the number in which death was certified as due to lung cancer was 499, which is almost identical with the number expected. Moreover, it may be noted that the experience of the standard population leads to estimates for the expected numbers of lung cancer deaths among two of the other groups of " non-nickel " workers which are reasonably close to the numbers observed. For the second explanation to be valid, it would be necessary for the mortality among nickel workers from all " other causes " to be only one-fifth of the national mortality—and this is certainly unreasonable. From knowledge of the mortality of industrial workers in general it is, on the contrary, more likely that by virtue of their social status, the total " other cause " mortality of the nickel workers was somewhat higher than that in the non-industrial sections of the community.

It is extremely unlikely that any substantial proportion of the deaths attributed to lung cancer were falsely diagnosed as a result of a bias in favour of diagnosing lung cancer among nickel workers. For if this had been so, it must be presumed that there would have been a deficiency of deaths attributed to those other causes which could most easily be confused with cancer of the lung, namely, other types of cancer and other respiratory diseases. In fact, of the 139 deaths among nickel workers during the period 1948-56, which were not attributed to cancer of the lung or cancer of the nose, 25 were attributed to other types of cancer and 21 to other respiratory diseases. Data for the causes of death, other than what was required to place them in one of the other categories shown in Tables 1 and 2, were not extracted for the non-nickel workers; but an estimate of the expected proportions attributable to " other causes " and to " other respiratory disease " can be obtained from the national mortality data for men of the same ages in England and Wales during the same period. The estimated numbers are 22 and 25 out of 139 respectively. The number of lung cancer deaths among the nickel workers might also have been artificially increased if there had been a specific tendency to describe as nickel workers men who had died of lung cancer and who, after employment at the refinery, had taken up some other occupation. Evidence that a bias of this type may, in the case of coal-miners,

*The few men whose ages at death were not known were presumed to have been distributed among the age groups in the same proportions as the men whose ages were known.

contribute to the excess mortality which is recorded on death certificates for this occupation has been obtained by Heasman, Liddell, and Reid (1958). It is, however, unlikely that such a factor should have biased the present results to an important extent, since the excess mortality has been practically constant since 1938 (see Table 4) and has shown no tendency to increase since the disease was prescribed in 1949. It is concluded, therefore, that the only reasonable interpretation of the results is that the high proportion of lung cancer deaths among nickel workers was due to an excess mortality from the disease and that, in the period 1948-56, the risk of dying from the disease was approximately five times " normal ".

Not all the workers appear to have been equally at risk. Of the 48 nickel workers whose deaths were attributed to lung cancer during this period, 28, or 58%, were described as having been employed directly on the process (that is, " processman " or " process worker "); on the other hand, the proportion of men whose deaths were attributed to causes other than cancer of the lung or nose and who were similarly described was somewhat smaller—54 out of 139 or 39%. The numbers of deaths from lung cancer expected among the process and the non-process workers are estimated to have been 3·93 and 5·95 respectively, so that on this basis the risk among the process workers appears to have been approximately double that among the other employees (28 observed to 3·93 expected compared with 20 observed to 5·95 expected, ratios of 7·1 to 1 and 3·4 to 1). Some of the non-process workers are, however, likely to have been employed as process workers at some time previously or to have had some closer contact with the specific process (for example, gatekeeper, labourer, and fitter). The relative risks to these two groups cannot, therefore, be satisfactorily measured from the present data and it is possible that the real difference is much greater.

TABLE 4

COMPARISON BETWEEN OBSERVED AND EXPECTED NUMBERS OF DEATHS FROM CANCER OF LUNG IN FOUR OCCUPATIONAL GROUPS IN 1938-47 AND 1948-56

Period	No. of Deaths	Nickel Workers	Men in Other Selected Occupations	Steel Workers	Colliery Workers
1938-47	Expected from the experience of men in "all other occupations"	2·61	0·89	13·12	20·67
	Observed	36	0	22	8
	Observed as % of expected	1,379	—	168	39
1948-56	Expected from the experience of men in "all other occupations"	5·86	4·27	37·62	56·89
	Observed	39	5	45	23
	Observed as % of expected	666	117	119	40

Lung Cancer in Other Special Occupations

In contrast to the nickel workers, some part of the discrepancy between the observed and expected numbers of lung cancer deaths among the colliery workers may be attributed to an abnormal death rate from " other causes ". According to the preliminary data on occupational mortality in England and Wales in 1950 (Registrar General, 1954), the death rate from all causes other than lung cancer among coal-miners aged 20-64 years was 20% above the average for the whole country. If, therefore, the numbers of deaths from " other causes " among the coal-miners are reduced by one-sixth (20/120), the expected number of lung cancer deaths becomes 126·80, and, in this case, the observed number is 58% of the expected. The mines in the area studied are, however, anthracite mines and anthracite miners in South Wales have suffered a higher mortality than other miners. In 1930-32, for example, the standardized mortality ratio for all coal workers below ground aged 20-65 years was 105, but it was 143 for the workers below ground in the anthracite mines of South Wales (Registrar General, 1938). If therefore, this difference has persisted in more recent periods the expected number of lung cancer deaths among miners should be reduced still further. The mortality from lung cancer among coal-miners in Britain has consistently been recorded as lower than that for all men and according to the occupational mortality data for 1950 was, at ages 20-64 years, 69% of the general rate. The present method of investigation would, therefore, appear to have provided a reasonably accurate estimate of mineworkers' mortality from this disease.

Lung cancer mortality among the five groups of workers included in " other selected occupations " will be discussed in another report.

Nasal Cancer

In the study of nasal cancer it is not possible to use quite the same technique, since the disease is normally very rare and the number of deaths shown in Table 1 due to nasal cancer among the men in " all other occupations " is very small. A more reliable estimate of the expected number of deaths might be obtained by using the whole group of non-nickel workers as a standard. This is vitiated, however, by the fact that the risk among the nickel workers appears to have been relatively so great that the inclusion of a small number of deaths of ex-nickel workers among the deaths of men who were last employed in some other occupation has

artificially increased the mortality from nasal cancer among the other workers in the area. Thus, in the four areas studied there were 12 deaths from nasal cancer during the period 1948-56 among men who were not nickel workers at the time of their death. The relatives of 10 of them were traced and it was learnt that four had been employed at the nickel refinery at some time. Similarly, in the two areas for which information was available back to 1938, four deaths from cancer of the nose were found to have occurred during the period 1938-47 among men who were not nickel workers at the time of death. Relatives of all these men were traced and it was discovered that three of them had previously been nickel workers. In all, therefore, at least seven out of the 16 non-nickel workers resident in the area who died of nasal cancer may at some time have been exposed to the particular hazard which is being studied.

In these circumstances, it is preferable to use the national data to provide an estimate of the expected mortality. Detailed figures have been published for the numbers of deaths attributed to a group of upper respiratory cancers consisting of cancer of the nose, nasal cavities, middle ear and accessory sinuses for each year since 1950, and figures for the total numbers of these cancers by sex have been published for the years 1940-49. Since the crude male death rate has been practically constant since 1942 (varying only from 5 to 6 per million), and since the deaths attributed to nasal cancer in Tables 1 and 2 include all the deaths which would have been classified by the Registrar General in this category—and no others—the national data provide a reasonable basis for comparison with the data collected in the present investigation. If, therefore, the whole male population of England and Wales is taken as the standard population and the same method of estimation is used as was used previously, estimates of the expected numbers of deaths from nasal cancer can be obtained. The results are shown in Table 5. From Table 5 it appears that the mortality from nasal cancer among the nickel workers during the period 1948-56 has been about 150 times higher than normal.

TABLE 5

COMPARISON BETWEEN OBSERVED AND EXPECTED NUMBERS OF DEATHS FROM CANCER OF NOSE AMONG NICKEL AND NON-NICKEL WORKERS

Population	No. of Deaths from Cancer of Nose		Ratio of Numbers Observed and Expected
	Observed	Expected	
Nickel workers:			
Four areas, 1948-56	13	0·082	159:1
Two areas, 1938-47	16	0·066	242:1
All areas available, 1938-56	29	0·148	196:1
Non-nickel workers:			
Four areas, 1948-56	12*	8·279	—
Two areas, 1938-47	4*	2·132	—
All areas available	16*	10·411	—

*Including several deaths among men with a history of previous employment in the nickel refinery: four in the period 1948-56 and three in 1938-47.

As previously with lung cancer, the risk does not appear to have been distributed equally among all the workers. Of the 29 nickel workers whose deaths were attributed to nasal cancer during the whole period 1938-56, 19, or 66%, were described as having been last employed before death directly on the process; the proportion of men who were similarly described and whose deaths were attributed to causes other than cancer of the lung or nose was 99 out of 231, or 43%. The numbers of deaths from nasal cancer expected among these two groups of workers are estimated to have been 0·064 and 0·084, so that on this basis the risk among the process workers appears to have been approximately two and a half times that among the other employees (19 observed to 0·064 expected compared with 10 observed to 0·084 expected, ratios of approximately 300 to 1 and 120 to 1). It must, however, be stressed again that the present data are unsatisfactory for estimating the relative risks among different occupational groups within the industry and the real difference may have been very much greater.

The total number of deaths registered among non-nickel workers during the whole period 1938-56 is somewhat larger than the expected number (16 against 10·4), but seven of these deaths occurred in men who are known to have been nickel workers previously. If these seven deaths are excluded the agreement is close and it may be concluded that the estimates of the numbers of deaths expected are reasonably accurate.

Secular Changes in Risk from Cancer of the Lung and Nose

To test the extent to which the risks have altered it is necessary to examine data collected over a long period of years since the induction period before the appearance of cancer is generally long. In the present case, data adequate for this purpose are available for only two of the four areas which were originally studied; these have been shown in Table 2. The men who were employed in " all other occupations " and were resident in these two areas have been used as the standards and the expected numbers of deaths attributable to cancer of the lung have been calculated by the technique described previously (working, however, with 10-year instead of five-year age groups, because of the smaller numbers). The results obtained are shown in Table 4. From these figures it would appear that

the specific risk of lung cancer in the industry has decreased from about 14 times " normal " to about seven times " normal ". This change, however, cannot be regarded as evidence of a decrease in risk among the nickel workers since the " normal " risk of lung cancer increased substantially during the period in question. In fact the excess over expectation of lung cancer deaths among the nickel workers was 3·3 per year during 1938-47 and 3·7 per year during 1948-56. Similarly, if the national data are used to estimate the numbers of deaths from nasal cancer expected in the two periods, it appears that the average excesses were 1·6 and 1·4 deaths per year. Clearly cases are still occurring and there has not as yet been any substantial change in their number.

On the other hand, from the data in Table 6, it is clear that the distribution of the ages at death has changed for both types of cancer. The change is particularly striking for cancer of the nose, for which the average age at death has increased by 6·2 years from 59·6 to 65·8 years. For cancer of the lung the increase is less marked, but it is still appreciable (an average increase of 3·3 years from 57·0 to 60·3 years). These changes may be regarded as evidence that the greatest risk occurred at some time in the past; for, in this situation, the average age of the men who suffered the heaviest exposure, and who may be presumed to suffer the heaviest specific mortality, must be expected to increase steadily with the passage of time. Further, for neither type of cancer is there any evidence of an increased mortality among men who were aged less than 50 years during the period 1948-56. It is clear, therefore, that there is no present evidence of any excess risk among men who, by virtue of their age, must have begun to be employed at the refinery after 1924. This is substantiated by Morgan (1958) who has made a detailed study of the occupational histories of the employees known to the industry to have died of cancer. He has found that none of those who started to work at the refinery after 1924 has died of cancer of the nose and only six of them have died of cancer of the lung. An estimate based on the national mortality rates for lung cancer suggested that if the risk had been entirely eliminated the expected number of lung cancer deaths would have been nine.

TABLE 6

AGE DISTRIBUTION OF DEATHS FROM CANCER OF LUNG AND OF NOSE AMONG NICKEL WORKERS IN 1938-47 AND 1948-56

Age (years)	Cancer of Lung		Cancer of Nose	
	1938–47	1948–56	1938–47	1948–56
Under 45	0	0	0	0
45–	4	1	0	0
50–	10	8	2	1
55–	10	7	7	1
60–	6	14	5	2
65–	3	7	2	7
70–	3	2	0	1
75 or more	0	0	0	1
All ages	36	39	16	13

Total Number of Respiratory Cancer Deaths Reported

The deaths from cancer reported in Tables 1 and 2 must be presumed to include a large proportion of the deaths due to cancer of the lung and nose which have been reported previously as occurring among nickel workers (Chief Inspector of Factories, 1952). The deaths in the Chief Inspector's report had, however, all occurred before the end of 1950 so that they do not include the 33 deaths from lung cancer and the 12 deaths from nasal cancer found in the present inquiry to have occurred among nickel workers and ex-nickel workers during the six years 1951-56. The total numbers of deaths now known to have occurred from cancer of the lung and nose during the period 1923 to 1956 are, therefore, at least 126 and 62 respectively.

In contrast, it may be noted that, in the present inquiry, only one nickel worker was found to have died from cancer of the larynx during the whole period 1938-56, and no other similar death has been reported for any earlier period.

Summary

Cancer of the lung and cancer of the nose have been prescribed as industrial diseases when they occur among certain classes of nickel workers. There is, however, no published evidence to show the size of the risks nor the extent to which they have been eliminated.

Data were collected from the records of deaths held by the medical officers of health for the districts in which workers at a nickel refinery lived. From the ratio of deaths attributed to lung cancer to deaths from causes other than cancer of the lung and nose among the other men resident in the same area an estimate was made of the number of lung cancer deaths which would be expected to have occurred among men employed in four specified occupational groups. During the years 1948-56, there were 139 deaths from " other causes " among nickel workers and 48 from lung cancer; the expected number of lung cancer deaths among them was 9·9. The excess did not appear to be due to a bias in favour of diagnosing lung cancer among nickel workers, and it is concluded that during 1948-56 the risk of nickel workers dying from the disease was approximately five times " normal ".

During 1948-56, 13 deaths among nickel workers were due to cancer of the nose. An estimate based upon the national mortality data suggested that the expected number of deaths was less than 0·1 and that the nickel workers' risk of dying from the disease was approximately 150 times "normal".

Comparison of the data for 1938-47 with those for 1948-56 provided no evidence of any substantial change in the annual number of deaths due to these specific diseases. There was, however, an increase in the average age at which death occurred and no excess in mortality was apparent at ages under 50. It is, therefore, reasonable to believe that the hazard has been largely or completely removed in the last 35 years.

The total numbers of deaths from these two diseases which are now known to have occurred among British nickel workers are: cancer of the lung, 126; cancer of the nose, 62.

I am most grateful to Dr. G. M. Davies, Dr. E. B. Meyrick, and Dr. H. R. Stubbins, medical officers of health, for making their records available for examination and for the assistance given by them and by their staffs. I am also very grateful for the assistance of the health visitors, who succeeded in obtaining occupational histories from such a high proportion of those non-nickel workers who had died of cancer of the nose, and to Miss K. Jones and Miss J. Parrish who extracted the greater part of the data.

References

Amor, A. J. (1939). Bericht über den VIII. internationalen Kongress für Unfall medizin und Berufskrankheiten, Frankfurt A-M, 1938, Vol. 2, p. 941. Thieme, Leipzig.

Chief Inspector of Factories (1952). Annual Report of the Chief Inspector of Factories for the Year 1950, p. 145. H.M.S.O., London.

Heasman, M. A., Liddell, F. D. K., and Reid, D. D. (1958). *Brit. J. industr. Med.*, **15**, 141.

Løken, A. C. (1950). *T. norske Laegeforen.*, **70**, 376.

Morgan, J. Gwynne (1958). *Brit. J. industr. Med.*, **15**, 224.

Registrar General (1938). Decennial Supplement England and Wales, 1931. Part IIA. *Occupational Mortality*. H.M.S.O., London.

—— (1954). Decennial Supplement England and Wales, 1951. Part I. *Occupational Mortality*. H.M.S.O., London.

Brit. J. industr. Med., 1958, **15**, 224.

SOME OBSERVATIONS ON THE INCIDENCE OF RESPIRATORY CANCER IN NICKEL WORKERS

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By far the greater part of all nickel refined in this country is dealt with by the Mond Nickel Company at their Clydach Refinery, near Swansea in South Wales. An inquiry at Clydach works has revealed the following facts: (*a*) No case of nose cancer has occurred among men who first entered employment there after 1925; (*b*) the incidence of lung cancer among these same men has been no higher than that in the country as a whole.

The purpose of this paper is to show how these facts have been established. The nature of the process used at Clydach is described, and the history of the investigation of the problem is given.

The Process

The Clydach Refinery was started in 1902 for the production of nickel by the carbonyl process. During the 55 years it has operated there have been many changes in raw materials, and improvements in the process and equipment.

Nickel ore is mined in Canada. The composition of the ore varies somewhat throughout the ore body but a typical "rich" ore contains about 2·5% of nickel, 30% of iron, 25% of silica, 2 to 4% of copper, and small amounts of cobalt, selenium, tellurium, silver, and the precious metals.

Preliminary concentrating and refining operations are carried out at the mines, and the material is received at Clydach in the form of a "matte" containing some 80% metals.

The process adopted at Clydach may be divided into three periods:—

Period 1 (1902-1933).—The raw material contained 40 to 45% nickel and 35 to 40% copper. Production of copper sulphate was on a large scale during this period.

Period 2 (1933-1953).—The raw material contained less than 3% copper. The sulphur content was at first high (over 20%) but this was reduced to 7%, and later to about 0·5%. Most of the copper was returned to Canada and very little copper sulphate was made (none for the period 1938-46 inclusive).

Period 3 (1953 to Date).—Raw material contained sinter (3% copper). A new, "direct wet treatment" process at Clydach replaced the Orford process. All copper was converted to copper sulphate for sale.

Period 1902-1933.—The process consisted essentially of the following:—

(*a*) The copper-nickel sulphide ores were smelted to a bessemer matte containing approximately 35% copper, 46% nickel, 0·8% iron, 17% sulphur. This process took place in Canada and the matte was shipped to Britain.

(*b*) At the Clydach refinery the matte was first crushed and ground.

(*c*) This matte was calcined to produce mixed oxides of copper and nickel (calcination).

(*d*) The greater part of the copper was leached out with sulphuric acid (copper extraction).

(*e*) The nickel oxide was reduced to an impure nickel powder (reduction).

(*f*) The reduced nickel was acted upon with carbon monoxide at about 50° C., to form a gas called nickel carbonyl (volatilization).

(*g*) The carbonyl thus formed was heated to temperatures of about 200° C. so that pure nickel is deposited and carbon monoxide re-formed (decomposition).

Crushing and Grinding.—The matte as received was fed at regular intervals into Krupp ball mills and ground to pass through a 60-mesh sieve, approximately 220 microns. Each calciner had its own mill and the ground matte passed continually from mill to calciner by means of conveyors, elevators, and distributors.

First Type Calciner (1900-1911).—The ground matte was subjected to a calcining process in order to convert the sulphides into oxides. It was fed into calciners, consisting of long fireproof brick tunnels

which were heated by producer gas. The matte was agitated and moved along by means of three ploughshares fastened to a bar which was dragged through the heated matte on the calciner bed by means of a chain on either side of the plough.

Second Type of Calciner (1924).—These were of the straight line double-deck type, a preliminary roasting being carried out on the upper hearth and a finishing calcination on the lower. The matte was spread and conveyed by ploughs rotating on their own axes and circulating on endless chains. Eight ploughs were attached to each chain and the chain speed was such that it took about 12 hours for the matte to travel the whole length of the top and bottom hearths.

After calcination the original 17% sulphur in the matte was reduced to 1·5%, this being present as sulphides and sulphates.

Copper Extraction.—The calcine was conveyed mechanically to Krupp ball mills, where any lumps formed in the calciners were ground through 40-mesh screens. It was then treated with 12% sulphuric acid, whereby about 75% of the copper was dissolved.

Reduction and Volatilization.—The dried copper-extracted matte was conveyed to the nickel plants where the remaining operations for extracting the nickel were carried out.

On entering the plant the matte was passed through reducers in which the oxides were reduced. The reduced matte was then distributed between volatilizers, where the nickel was volatilized as carbonyl.

The volatilizers were similar in construction to the reducers, but no heating was necessary as the reaction

$$Ni + 4CO = Ni(CO)_4$$

is exothermic. The matte travelled down the volatilizer where it was brought into intimate contact with an upward stream of carbon monoxide.

Decomposition.—In the decomposing apparatus the nickel carbonyl came in contact with nickel pellets heated to a temperature of about 180° C. This caused the dissociation of the carbonyl, so that nickel was deposited on the pellets and carbon monoxide liberated.

Repetition of Extraction Processes.—The discharge still contained nickel which had not been volatilized as nickel carbonyl. It was therefore passed through the above series of operations again in order to effect further extraction.

The product of the last extracting operation was transferred to a concentrating plant, where it was successively oxidized and leached with sulphuric acid to remove the bulk of the base metals.

Concentrating Plant for Precious Metals.—The purpose of this was to take out copper and nickel from the concentrates, which came from the nickel sheds, in order to raise the percentage of precious metals as high as possible. The matte was calcined and sulphuric acid added to extract copper and nickel.

Period 1933-1953.—During these years, the Clydach plant and process underwent many important changes.

As the matte supplied from Canada had a high nickel and low copper content, the manufacture of copper sulphate was discontinued.

The original calciners with their individual Krupp mills were scrapped, and a large air-swept mill installed of sufficient capacity to handle all matte. Rotary hearth calciners were introduced in 1935 with conveyor feed and discharge; these effected a great improvement in calcination conditions. At the same time mechanical dust catchers and electrostatic precipitators were installed to recover dust previously carried forward to the main stacks.

The use of " soft roast sulphide " (7% sulphur) in the process and later of " sinter " (0·5% sulphur) has done much to improve conditions in the refinery.

In 1939 the old hand-fired water gas and producer gas producers were replaced by a modern gas plant in which the fuel is mechanically charged and most operations are automatically performed.

The substitution of high-nickel-content mattes for the original Bessemer matte increased the capacity of the nickel plants, as the extraction of nickel as carbonyl was more rapid and efficient. The number of reducers and volatilizers required for a given rate of feed was substantially reduced, and the higher concentration of nickel carbonyl in the gases from the volatilizers increased the capacity of the decomposers.

More complete and quicker extraction of nickel is achieved when the process is carried out at pressures above atmosphere. The first pressure process was started at Clydach in 1935. Much of the resulting nickel carbonyl was recovered in the liquid phase, and as such was fed into the atmospheric plants. The effect was not only to produce more pellets, but also to increase the carbon monoxide content of the volatilizer gases, and so improve the degree of extraction.

Period 1953 to Date.—The only fundamental change in process operations since 1953 has been the installation of the direct wet treatment plant, and the closing down of the Orford furnace.

Instead of smelting concentrate 2, discharged from the nickel plant, in the Orford furnace, this material is now calcined at a low temperature, and leached

first with water and then with dilute sulphuric acid. The residue is dried and smelted. By these means some 20% of the nickel, 65% of the cobalt, and 80% of the copper are recovered before smelting.

The smelt matte is crushed, ground, calcined, and fed to the old wet treatment plant for extraction of the base metals and preparation of precious metal concentrate.

All copper, coming into the works in the raw sinter, is now converted to copper sulphate for sale.

Statistical Investigations

After the carbonyl process had been in operation for about 30 years, several deaths from respiratory cancer occurred and Professor Bradford Hill was approached with a view to obtaining statistical information relating to the incidence of carcinoma of the respiratory system at the works. Bradford Hill found that not only was there an apparently abnormal incidence of carcinoma of the lung and nose in the refinery population from 1929 to 1938, but that this excess was confined to the process workers. An abstract of Bradford Hill's report of October, 1939, is as follows:—

(1) The numbers and ages of the workmen employed at the refinery and of pensioners on the books were available for two dates, namely April 28, 1931, and June 30, 1937. The age distribution did not vary appreciably between these dates and the mean of the two figures may therefore be taken as a reasonable representation of the population over the nine years of the inquiry 1929-1938. Annual figures for the population of all ages for these years give an average of 950 men. This figure, with the age distribution shown in Table 1, has been taken as the population exposed to risk of dying between 1929 and 1938.

(2) To this population was applied the age specific death rates of men in all England and Wales in the quinquennium 1931-35 for (*a*) all causes of death, (*b*) cancer of all sites, and (*c*) respiratory cancer. The "expected" deaths on this basis are compared in Table 2 with those actually observed.

TABLE 1

CALCULATION OF POPULATION AT RISK: 1929 TO 1938

Age	No. of Workmen and Pensioners		% Distribution		Mean % 1931 and 1937	Distribution of Population of 950
	1931	1937	1931	1937		
15–	13	36	1·55	3·42	2·49	24
20–	23	78	2·74	7·41	5·08	48
25–	205	234	24·47	22·22	23·35	222
35–	251	292	29·96	27·73	28·85	274
45–	230	230	27·44	21·85	24·65	234
55–	95	154	11·34	14·62	12·98	123
65–	16	25	1·91	2·37	2·14	20
75–85	5	4	0·60	0·39	0·50	5
All ages	838	1,053	100·01	100·01	100·04	950

TABLE 2

COMPARISON OF DEATHS EXPECTED AT RATES FOR MEN IN ALL ENGLAND AND WALES AND DEATHS OBSERVED IN REFINERY POPULATION

	Estimated Expected Deaths in 8¾ Years (1929–1938)	Observed Deaths in Same Period
All causes	84	105
All causes less cancer	72	67
Cancer all sites	12	38
Cancer of lung	1	16
Cancer of nose	0–1	11
Cancer less nasal and lung forms	10–11	11

(3) The results show that there were 105 observed deaths from all causes (excluding three deaths of office staff) and 84 expected at the national rates. Sub-division of these deaths by cause gives a very striking picture. From all causes less cancer, 72 deaths were expected and 67 were observed, only a very small difference. But from cancer as a whole 12 deaths only were expected and as many as 38 were observed, a very heavy excess.

This excess of cancer mortality lies entirely in two sites. From cancer of the lung only one death would be expected at the recorded rates for England and Wales; 16 were observed. Of nasal cancers, 11 were observed and, in the absence of national figures, certainly not more than one would be expected.

If these cancers of the lung and nose are excluded about 10 deaths from cancer of other sites would be expected; actually 11 were observed, a remarkably close concordance.

(4) The abnormal incidence of cancer of two sites can be further and informatively analysed. The population of the refinery can be broadly divided into two groups, the process and the non-process workers, the former including all the processes and the latter the workers in the power house, on plant repairs, electrical, mechanical, traffic, yard, superintendence, and general. The average numbers of each over the years in question were 438 process

TABLE 3

COMPARISON OF DEATHS IN PROCESS AND NON-PROCESS WORKERS

	No. of Deaths Recorded (June, 1929–January, 1938)	
	Process Workers	Other Workers
Respiratory causes	13	10
Heart disease and cerebral haemorrhage	15	17
Other causes (except cancer)	7	7
Total less cancer	35	34
Cancer: Nasal	11	–
Lung	15	1
Other sites	7	5
Total cancer	33	6
Total all causes	68	40

workers and 389 non-process workers. There were also rather more pensioners who had been process workers. In total, therefore, this group was rather larger and older than the group of non-process workers (the actual age distributions were unknown) and might be expected to suffer a slightly higher mortality. The deaths actually observed in each group are set out in Table 3. It will be seen that from 1929 to 1938 there were 108 deaths in all (including three deaths of office staff not included in Table 2).

From causes other than cancer there were 35 deaths of process workers and 34 of other workers, a position which perhaps rather favours the process workers if they are slightly the larger and older group.

From cancer of all sites there were 33 deaths of process workers and only six of other workers.

There is no material difference between the two groups in any broad cause group except cancer, and the excess here relates entirely to cancer of the two sites, nose and lung. Other forms of cancer are approximately equal (seven deaths amongst process workers, five amongst other workers).

(5) In short, not only does there appear to have been an abnormal incidence of cancer of the lung in the refinery population as a whole in 1929-1938, but it seems that this abnormality has been practically, probably entirely, confined to the process workers.

Carcinoma of the lung and nose in workers who were occupied in a factory where nickel is produced by decomposition of a gaseous nickel compound were included in the list of prescribed diseases in 1949.

It was thought that further investigation was necessary as it seemed that those entering the works after a certain period were not affected. In order to carry out this investigation, a register of all new employees was prepared.

This register (Appendix I) shows that between 1900 and 1957 there were 9,340 new entrants, and of these 131 (1·4%) developed cancer of the lung, and 61 (0·65%) developed cancer of the nose.

The minimum duration of service for a known case was one and a quarter years for carcinoma of the lung and six years for carcinoma of the nose. A truer picture of incidence is therefore given by excluding those new entrants who remained in employment less than one year. Between 1900 and 1929 there were 2,094 entrants who remained over one year; 131 (6·3%) of these developed cancer of the lung and 61 (2·9%) developed cancer of the nose.

From Appendix I it is evident that the incidence varied from year to year, and it was thought pertinent to enquire how this variation affected different groups of entrants.

The percentage of entrants, excluding those who remained in employment less than one year, who developed cancer of the lung or nose was therefore calculated. The results are given in Table 4 and Fig. 1.

The highest incidence of cancer of the lung and nose occurred in those workers who began work between 1905 and 1914. Owing to the very long lag period between exposure and development of cancer, there are probably a few deaths still to occur. There was a progressive fall until 1920, when the incidence rose, but fell again after 1924 (Appendix I). The lung cases were more numerous than the nose cases.

No cases of cancer of the nose and only six cases of cancer of the lung have been recorded in persons who entered the works for the first time after 1924. The expected number of cancer of the lung cases since 1924, calculated at the England and Wales rate for the various age groups, was four.

Fig. 2 shows the actual number of carcinoma cases, both nose and lung, according to year of entry.

In Appendix II an analysis is given of the occupations of men who were known to have suffered from nickel carbonyl poisoning and who later developed cancer of the lung or nose. The detailed occupations of those who entered in 1922-24 and who later developed cancer of the lung or nose are also given.

General data on the occurrence of cancer of the lung and nose are as follows:—

	Lung	Nose
Year of first reported cases	1927	1923
Number of cases up to December, 1957	131	61
Cases still alive	3	—
Youngest age at death	43	36
Oldest age at death	73	78
Shortest service before development of cancer (years)	1¼	6
Longest service before development of cancer (years)	43	42

TABLE 4

PERCENTAGE OF ENTRANTS WITH MORE THAN ONE YEAR'S SERVICE LATER DEVELOPING CARCINOMA OF LUNG OR NOSE

Year of Entry	Carcinoma of Lung (%)	Carcinoma of Nose (%)	Year of Entry	Carcinoma of Lung (%)	Carcinoma of Nose (%)	Year of Entry	Carcinoma of Lung (%)	Carcinoma of Nose (%)
1900–	15·1	1·9	1920–	6·6	1·3	1940–	0·6	—
1905–	15·8	9·6	1925–	0·9	—	1945–	0·1	—
1910–	13·0	10·8	1930–	0·4	—	1950–	—	—
1915–	1·7	0·9	1935–	—	—	1955	—	—

first with water and then with dilute sulphuric acid. The residue is dried and smelted. By these means some 20% of the nickel, 65% of the cobalt, and 80% of the copper are recovered before smelting.

The smelt matte is crushed, ground, calcined, and fed to the old wet treatment plant for extraction of the base metals and preparation of precious metal concentrate.

All copper, coming into the works in the raw sinter, is now converted to copper sulphate for sale.

Statistical Investigations

After the carbonyl process had been in operation for about 30 years, several deaths from respiratory cancer occurred and Professor Bradford Hill was approached with a view to obtaining statistical information relating to the incidence of carcinoma of the respiratory system at the works. Bradford Hill found that not only was there an apparently abnormal incidence of carcinoma of the lung and nose in the refinery population from 1929 to 1938, but that this excess was confined to the process workers. An abstract of Bradford Hill's report of October, 1939, is as follows:—

(1) The numbers and ages of the workmen employed at the refinery and of pensioners on the books were available for two dates, namely April 28, 1931, and June 30, 1937. The age distribution did not vary appreciably between these dates and the mean of the two figures may therefore be taken as a reasonable representation of the population over the nine years of the inquiry 1929-1938. Annual figures for the population of all ages for these years give an average of 950 men. This figure, with the age distribution shown in Table 1, has been taken as the population exposed to risk of dying between 1929 and 1938.

(2) To this population was applied the age specific death rates of men in all England and Wales in the quinquennium 1931-35 for (*a*) all causes of death, (*b*) cancer of all sites, and (*c*) respiratory cancer. The "expected" deaths on this basis are compared in Table 2 with those actually observed.

(3) The results show that there were 105 observed deaths from all causes (excluding three deaths of office staff) and 84 expected at the national rates. Sub-division of these deaths by cause gives a very striking picture. From all causes less cancer, 72 deaths were expected and 67 were observed, only a very small difference. But from cancer as a whole 12 deaths only were expected and as many as 38 were observed, a very heavy excess.

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TABLE 1

CALCULATION OF POPULATION AT RISK: 1929 TO 1938

Age	No. of Workmen and Pensioners		% Distribution		Mean % 1931 and 1937	Distribution of Population of 950
	1931	1937	1931	1937		
15–	13	36	1·55	3·42	2·49	24
20–	23	78	2·74	7·41	5·08	48
25–	205	234	24·47	22·22	23·35	222
35–	251	292	29·96	27·73	28·85	274
45–	230	230	27·44	21·85	24·65	234
55–	95	154	11·34	14·62	12·98	123
65–	16	25	1·91	2·37	2·14	20
75–85	5	4	0·60	0·39	0·50	5
All ages	838	1,053	100·01	100·01	100·04	950

TABLE 2

COMPARISON OF DEATHS EXPECTED AT RATES FOR MEN IN ALL ENGLAND AND WALES AND DEATHS OBSERVED IN REFINERY POPULATION

	Estimated Expected Deaths in 8¼ Years (1929–1938)	Observed Deaths in Same Period
All causes	84	105
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No cases of cancer of the nose and only six cases of cancer of the lung have been recorded in persons who entered the works for the first time after 1924. The expected number of cancer of the lung cases since 1924, calculated at the England and Wales rate for the various age groups, was four.

Fig. 2 shows the actual number of carcinoma cases, both nose and lung, according to year of entry.

In Appendix II an analysis is given of the occupations of men who were known to have suffered from nickel carbonyl poisoning and who later developed cancer of the lung or nose. The detailed occupations of those who entered in 1922-24 and who later developed cancer of the lung or nose are also given.

General data on the occurrence of cancer of the lung and nose are as follows:—

	Lung	Nose
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Year of Entry	Carcinoma of Lung (%)	Carcinoma of Nose (%)	Year of Entry	Carcinoma of Lung (%)	Carcinoma of Nose (%)	Year of Entry	Carcinoma of Lung (%)	Carcinoma of Nose (%)
1900–	15·1	1·9	1920–	6·6	1·3	1940–	0·6	—
1905–	15·8	9·6	1925–	0·9	—	1945–	0·1	—
1910–	13·0	10·8	1930–	0·4	—	1950–	—	—
1915–	1·7	0·9	1935–	—	—	1955	—	—

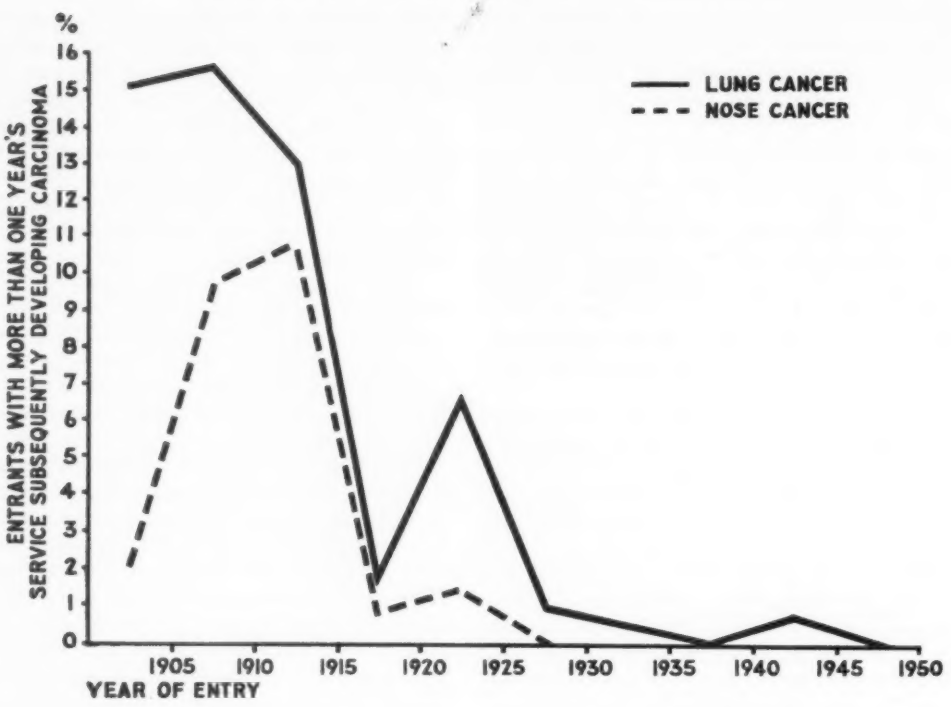

FIG. 1.—The incidence of carcinoma of the lung and nose according to year of entry in entrants with more than one year of service.

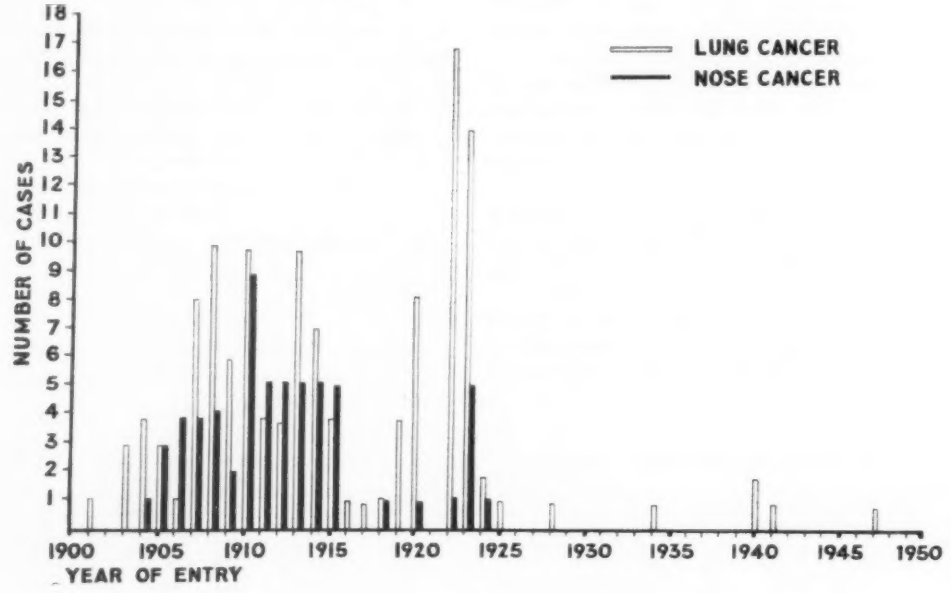

FIG. 2.—Number of cases of carcinoma of lung and nose according to year of entry.

The occurrence of cancer of the lung and nose in nickel workers is likely to be affected by the following factors:—(*a*) Length of service and " lag " period; (*b*) occupations followed; (*c*) materials involved; (*d*) preventive measures.

(a) Length of Service.—It has long been realized that a considerable time elapses between the exposure of an individual to risk and the occurrence of industrial cancer. This interval, for convenience called the " lag " period, may be as long as 25 years and perhaps even longer. It is this factor which accounts for the deaths that have occurred at Clydach in recent years.

The " lag " period is influenced by several factors such as age at entry into the occupation, length of service, variations in concentrations of carcinogen, and individual susceptibility.

In practice difficulty was experienced in establishing the exposure period in many cases. The term " labouring " appears in most men's history, and at first this occupation was not considered hazardous, but further investigation showed that labourers might be called upon to work in any part of the plant. Again, the date of onset of the disease was sometimes difficult to establish with certainty. The length of service from entry to the works until death was therefore recorded. The results are given in Table 5 and Fig. 3.

It is interesting to note that the time from first exposure to death is similar to the time lag of bladder cancer in certain chemical workers, of lung cancer in chrome workers, and in miners at Schneeberg.

TABLE 5
NUMBER OF YEARS BETWEEN ENTRY TO WORKS AND DEATH (ALL CASES DYING UP TO DECEMBER 31, 1957, ARE INCLUDED)

No. of Years' Service	Cancer of Lung	Cancer of Nose
	No. of Deaths	No. of Deaths
0–	6 (4·6%)	—
5–	3 (2·3%)	4 (6·5%)
10–	3 (2·3%)	5 (8·1%)
15–	11 (8·4%)	9 (14·7%)
20–	27 (20·6%)	23 (39·2%)
25–	31 (23·6%)	11 (18·0%)
30–	25 (19·1%)	6 (9·6%)
35–	16 (12·2%)	2 (3·2%)
40–	9 (6·9%)	1 (1·6%)
	131 (100·0%)	61 (100·9%)
Mean 26·9 S.D. ± 6·15		Mean 22·65 S.D. ± 7·0

(b) Occupations Followed.—Table 6 gives the number of patients who worked at a single job at Clydach during the period 15 to 25 years before death, and Table 7 the patients who worked at more than one job. These tables suggest that the occupations meriting special attention are calcination, the production of copper sulphate and nickel sulphate, and furnace work.

Table 6 indicates that the majority of both lung and nose cancers occurred in those engaged in what were formerly dusty processes. The highest

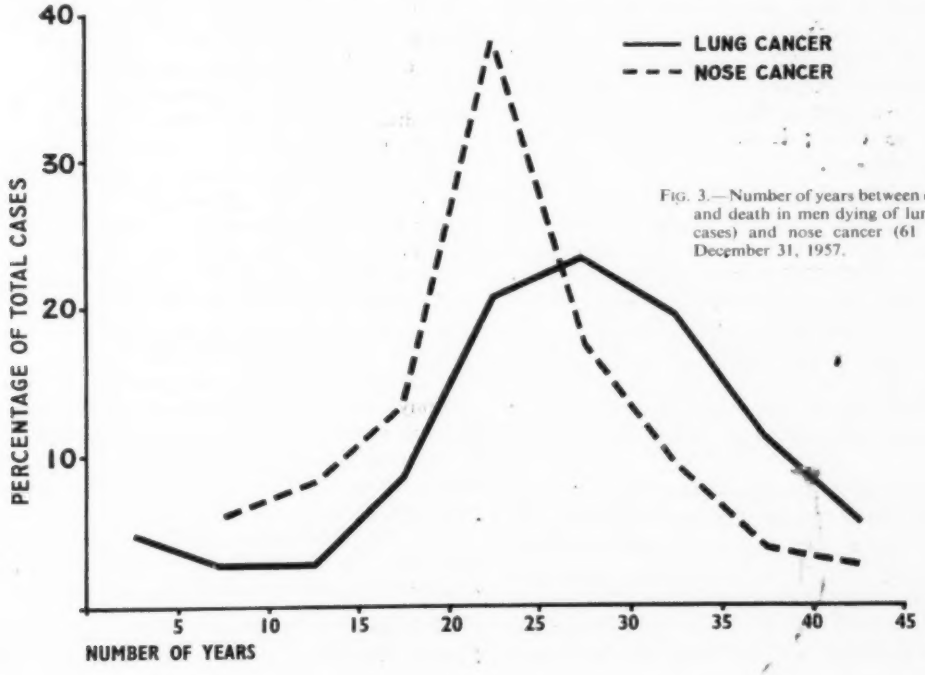

FIG. 3.—Number of years between entry to works and death in men dying of lung cancer (131 cases) and nose cancer (61 cases) up to December 31, 1957.

TABLE 6

OCCUPATIONAL INCIDENCE IN VARIOUS PROCESSES IN MEN WORKING IN ONE DEPARTMENT ONLY DURING 15 TO 25 YEARS BEFORE DEATH

Process or Department	Average Annual Population	No. of Cases of Carcinoma of Lung	No. of Cases of Carcinoma of Nose
Gas producers	—	1	—
Calcination	58	14	14
Copper sulphate	87	20	8
Nickel sulphate	57	4	3
Furnaces	36	2	5
Concentrate	26	2	1
Nickel sheds	163	5	1
Fitters	80	9	1
Totals	507	57	33

TABLE 7

MEN WORKING IN MORE THAN ONE DEPARTMENT DURING 15 TO 25 YEARS BEFORE DEATH

Department	No. of Cases of Carcinoma of Lung	No. of Cases of Carcinoma of Nose
Calciners + nickel sheds	4	1
+ copper sheds	7	9
+ nickel sulphate	1	—
+ furnaces	1	—
Copper sheds + nickel sulphate	4	4
+ furnaces	1	—
Nickel sheds + copper sheds	9	3
+ furnaces	2	—
Non-process workers	7	—
Miscellaneous	36	11
Gas producers + furnaces	1	—
+ copper sheds	1	—
Totals	74	28

frequencies were in the calciners, copper sulphate plant workers, furnace workers, crushing and grinding department workers, and in those transporting matte from the calciners to the nickel sheds.

The dust in the calcination department was of a very fine and pyrophoric nature. In the copper sheds there was a fine copper sulphate powder which had a local corrosive effect; it also contained certain arsenical compounds.

(c) Materials Involved.—Much has been written to indicate the nature, number, and great variety of the chemical carcinogens. Those that might have been present in Clydach are: (i) Radioactive substances, (ii) arsenic, and (iii) nickel carbonyl.

(i) *Radioactive Substances.*—Tests carried out by means of a sensitive electroscope at the works and also by photographic, electroscopic, and emanation methods in the laboratory yielded no evidence of radioactivity of the nickel matte at any stage in the process.

(ii) *Arsenic.*—Arsenic was present both in the matte and in the sulphuric acid used for extraction of copper sulphate. Before 1921 the sulphur smelt matte contained a considerable quantity of arsenic derived from sulphuric acid which had been used for the extraction of copper. The arsenic remained in the matte throughout the process until it came to the melting furnaces and calciners as a copper-nickel arsenite. A record was maintained of the amount of arsenic present in the sulphuric acid used up to 1927, and is presented in Table 8.

TABLE 8

AMOUNTS OF ARSENIC IN SULPHURIC ACID

Year	Amount of Arsenic (tons)	Year	Amount of Arsenic (tons)	Year	Amount of Arsenic (tons)	Year	Amount of Arsenic (tons)
1903	3·0	1910	27·0	1916	68·8	1922	1·1
1904	6·7	1911	30·0	1917	102·5	1923	0·63
1905	7·2	1912	34·0	1918	89·5	1924	0·64
1906	12·2	1913	40·0	1919	108·7	1925	0·35
1907	18·4	1914	50·0	1920	13·6	1926	0·25
1908	25·6	1915	60·0	1921	9·4	1927	Nil
1909	22·0	—	—	—	—	—	—

From 1921 onwards the quantity of arsenic contained in the acid fell, but it was not until 1924 that all the old stock of acid was used. Since 1926 the acid used has been practically free of arsenic.

Amor (1939) found that slight cases of arsenic poisoning did occur in nickel workers, together with characteristic skin rashes and oedema of the scrotum. From an examination of sickness records before 1934 he noted that several cases of cholaemia were reported and that after 1920 they almost completely ceased; the relationship of this to arsenic poisoning, if any, is unknown.

(iii) *Nickel Carbonyl.*—The suggestion that respiratory cancer is in some way linked with nickel carbonyl is not supported for the following reasons:

(1) There has been no material change in the process in the nickel sheds where nickel carbonyl gas has been produced over the last 50 years, to which could be attributed the improvement in the incidence of respiratory cancer which has occurred since 1925.

(2) In the nickel sheds, in addition to the carbonyl hazard, there was also a dust hazard where the matte was brought in and discharged from the plant. Before 1925 the sulphuric acid used contained considerable amounts of arsenic. No case of carcinoma of the nose has occurred in men who entered the works after 1924 and the incidence of cancer of the lung in these men is not above the national average.

(3) Of 131 lung and 61 nose carcinoma cases, only 15 had suffered from the effects of nickel carbonyl inhalation, and of these 10 were lung cases and five were nose cases. Most of these cases had been engaged in various occupations in the works. In five of the cases, gassing occurred less than four years before death.

(4) Løken (1950) has reported carcinoma of the lung in a Norwegian works where nickel is refined other than by the carbonyl process.

(d) Preventive Measures.—As a result of the suggestion that arsenic might be the carcinogenic agent

responsible for the high incidence of respiratory cancer, measures were taken to exclude metallic arsenides from the process, to provide arsenic-free sulphuric acid, and to suppress dust at every stage of the process. Details of the various improvements made are given below:—

In 1910, a plough type of calciner, which operated from 1902 to 1911, was changed to double-deckers with rotary rakes which, although very dusty, were an improvement on the first type.

In 1922, arsenic-free sulphuric acid was used. Nose and mouth respirator pads were issued.

In 1924, calciners were shortened and improved.

In 1929, the copper sulphate plant was closed down.

In 1934, the mattes were changed and now contained only 2% copper instead of 35%, and only 2% sulphur instead of 20%.

In 1935, Lodge Cottrell electrostatic precipitators diminished the amount of dust emitted from the stacks. Also from that date the whole of the crushing and grinding of the material is now done in a central grinding plant which is virtually dust free. Formerly the crushing and grinding was done separately in each plant by means of Krupp crushers, which were very dusty.

In 1936, new calciners were installed. The old type led to underground flues which had to be cleaned very frequently, and it is significant that most of the nose cases occurred amongst the men who were engaged in cleaning these flues. The new calciners are in a well-ventilated room and the flue gasses from these calciners are taken to two Lodge Cottrell electrostatic precipitators.

In 1937, a new type of closed bogie was used instead of the open trucks, which has an automatic emptying device fitted to it with a new suction feed apparatus which makes it possible to feed this matte into the nickel sheds without making the slightest dust if used properly. Also new feed elevators were introduced to the nickel sheds.

In 1944, the matte was free from sulphur.

Medical Control

Comprehensive pre-employment medical examinations, including a chest radiograph, are now carried out. Routine examinations are undertaken annually and particular attention is paid to any possible manifestation of industrial disease; the annual re-examination includes a chest radiograph. All employees are medically examined before return to work if they have been absent on sick leave for more than one month. Regular dust counts are undertaken in all dusty processes; the plant superintendents are given the results of these tests and they are encouraged to keep the counts at a low level.

Summary

(1) At Clydach Works, the incidence of cancer of the lung and nose among workers engaged in the refining of nickel and the preparation of nickel and copper salts was found to be greater than that of the general population. One hundred and thirty-one cases of lung cancer and 61 of cancer of the nose are reported. A description is given of the nickel carbonyl process.

(2) The increased incidence of cancer of the lung and nose, which has not been noted amongst workers engaged in processes involving the use of metallic nickel, appeared to be related to: (*a*) Dusty occupations rather than to occupations where nickel is dealt with as a gaseous compound, and/or (*b*) drying and powdering of copper sulphate, and/or (*c*) the sulphuric acid used before 1921 which was far from pure and contained arsenic.

(3) As an index of the action of any carcinogenic material which had been present at the Clydach Works, the incidence of nasal cancer was far more significant than that of lung cancer. No deaths from nasal cancer have been recorded from workers engaged after 1924, at which date increased precautions were taken against dust.

(4) It is considered that dust, possibly the heated calcined dusts, contained the carcinogen. Before 1924 this dust probably contained arsenic from the sulphuric acid used. After taking into account (i) the period of exposure to the hazard (minimum one year); (ii) the long lag period between exposure and the appearance of the first signs and symptoms; and (iii) the survival period after diagnosis (on the average between 18 and 24 months), it is not unreasonable to draw the inference that carcinogenic material may possibly have been present in the heated calcined dusts—possibly in their arsenic content.

(5) The average period from entry to the works to death was 27 years in lung cancer cases and 22 years in nose cancer cases.

(6) Deaths from carcinoma of the lung and nose which occurred in men not employed in the calcination process may be attributable to the fact that they came into contact with calcined dusts during the course of their employment.

It is a pleasure to express my grateful thanks to my staff for their great help in the preparation of this paper.

References

Amor, A. J. (1939). Bericht über den VIII. internationalen Kongress für Unfallmedizin und Berufskrankheiten, Frankfurt A.M., 1938, Vol. 2, p. 941. Thieme, Leipzig.

Bradford Hill, A. (1939). Report to Mond Nickel Company.

Løken, A. C. (1950). *T. norske Laegeforen*, **70**, 376.

APPENDIX I

Register of Employees

A register was prepared of the new entrants each year; no re-engaged person was included. The following particulars were recorded in the register:—

(1) The number of entrants.

(2) The number employed annually, *i.e.* the establishment.

(3) Numbers employed by years-of-service groups: under one year, one-10 years, 11-20 years, and those who remained over 20 years.

(4) Number of cases of carcinoma of the lung and nose.

(5) Percentage of the entrants who developed (*a*) carcinoma of the lung, (*b*) carcinoma of the nose.

(6) The number of deaths due to other causes.

Table 9 gives the figures obtained from this register. In calculating the percentages of new entrants who developed carcinoma of the lung or nose, those with less than one year's service have been omitted, as the minimum duration of service for a known case was one and a quarter years for carcinoma of the lung and six years for carcinoma of the nose.

The total number of new entrants from 1900 to December 31, 1957, was 9,340. The Company has a pension scheme which enables it to keep records of all pensioners, wherever they may live; they are visited annually and thus the Company is able to keep in touch with them. When pensioners die a death certificate must be furnished in order that their dependants may obtain a death benefit and the cause of death is, therefore, recorded in every case.

The labour turnover is equal to the average for the area and only a few men change their employment and leave the district. A scrutiny of the local death register

TABLE 9

CASES OF CARCINOMA OF LUNG AND NOSE BY YEARS-OF-SERVICE GROUPS AND EXPRESSED AS A PERCENTAGE OF ENTRANTS WITH MORE THAN ONE YEAR'S SERVICE

Year of Entry	New Entrants	No. of Men Employed (Establishment)	Years of Service and No. of Cases												No. of Cases		Cases % of Entrants with More than One Year's Service		No. of Deaths from Other Causes
			Under 1 Year			1–10 Years			11–20 Years			Over 20 Years							
			No.	Cancer Lung	Cancer Nose	No.	Cancer Lung	Cancer Nose	No.	Cancer Lung	Cancer Nose	No.	Cancer Lung	Cancer Nose	Carcinoma of Lung	Carcinoma of Nose	Carcinoma of Lung	Carcinoma of Nose	
1900	13	13	10	—	—	—	—	—	1	—	—	2	—	—	—	—	—	—	—
1901	89	102	83	—	—	4	1	—	2	—	—	—	—	—	1	—	(16·7)	—	—
1902	185	125	171	—	—	—	—	—	4	—	—	10	—	—	—	—	—	—	3
1903	109	190	98	—	—	1	—	—	—	1	—	10	2	—	3	—	(27·3)	—	2
1904	27	230	8	—	—	—	—	—	—	—	—	19	4	1	4	1	(21·0)	(5·2)	—
	423		370			5			7			41			8	1	15·1	1·9	
1905	32	370	14	—	—	5	—	—	2	—	1	11	3	2	3	3	(16·7)	(16·7)	—
1906	69	395	32	—	—	3	—	—	1	—	1	33	1	3	1	4	(2·7)	(10·8)	6
1907	85	475	34	—	—	19	—	—	3	—	3	29	8	1	8	4	15·7	7·8	3
1908	78	470	31	—	—	21	—	—	—	—	—	26	10	4	10	4	21·3	8·6	—
1909	53	545	29	—	—	7	—	—	—	1	1	17	5	1	6	2	(25·0)	(8·3)	—
	317		140			55			6			116			28	17	15·8	9·6	
1910	143	590	52	—	—	45	—	1	2	—	1	44	10	7	10	9	11·0	9·9	1
1911	116	600	69	—	—	24	—	—	2	—	2	21	4	3	4	5	8·5	10·6	4
1912	91	670	56	—	—	12	—	—	3	—	2	20	4	3	4	5	(11·4)	(14·3)	2
1913	221	825	168	—	—	16	—	1	2	3	—	35	7	4	10	5	18·9	9·4	4
1914	495	990	452	—	—	6	—	—	9	1	—	28	6	5	7	5	16·3	11·6	7
	1,066		797			103			18			148			35	29	13·0	10·8	
1915	481	1,200	289	—	—	159	—	—	5	—	1	28	4	4	4	5	2·1	2·5	3
1916	440	1,360	155	—	—	273	1	—	3	—	—	9	—	—	1	—	0·4	—	10
1917	286	1,350	180	—	—	78	—	—	—	—	—	28	1	—	1	—	0·9	—	9
1918	290	920	276	—	—	2	—	—	—	1	1	12	—	—	1	1	(7·1)	(7·1)	12
1919	295	775	225	—	—	29	—	—	7	2	—	34	2	—	4	—	5·7	—	15
	1,792		1,125			541			15			111			11	6	1·7	0·9	
1920	173	415	145	—	—	1	2	—	6	1	—	21	4	1	7	1	(25·0)	(3·6)	8
1921	152	600	59	—	—	55	—	—	1	—	—	37	—	—	—	—	—	—	4
1922	346	1,050	129	—	—	113	—	—	4	1	—	100	16	1	17	1	7·8	0·46	5
1923	415	1,090	236	—	—	120	2	1	5	2	—	54	10	4	14	5	7·8	2·8	3
1924	137	1,085	52	—	—	53	—	—	3	—	1	29	2	—	2	1	2·4	1·2	5
	1,223		621			342			19			241			40	8	6·6	1·3	
1925	33	970	14	—	—	1	—	—	3	—	—	15	1	—	1	—	(5·3)	—	3
1926	79	1,100	20	—	—	17	—	—	3	—	—	39	—	—	—	—	—	—	7
1927	48	1,210	8	—	—	18	—	—	3	—	—	19	—	—	—	—	—	—	11
1928	280	1,414	93	—	—	153	1	—	4	—	—	30	1	—	2	—	1·1	—	12
1929	140	1,185	119	—	—	5	—	—	1	—	—	15	—	—	—	—	—	—	10
	580		254			194			14			118			3	—	0·9	—	

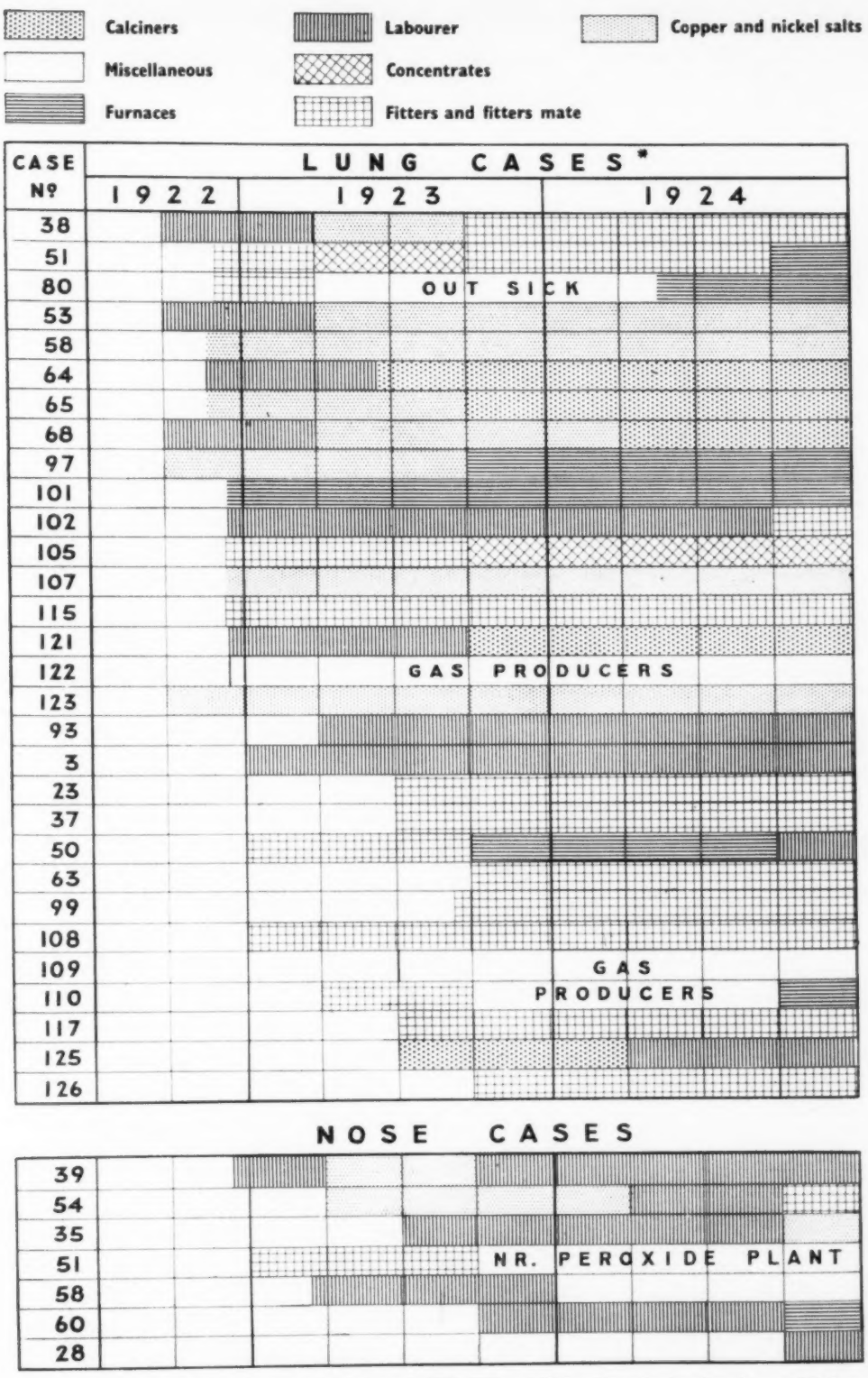

FIG. 4.—Occupations of those who entered the industry in 1922, 1923, and 1924 and later developed carcinoma of the lung or nose.

*The detailed occupations of three lung cases could not be traced.

has yielded a few names in addition to those of pensioners. Two additional cases were thus discovered by W. R. S. Doll (personal communication), during his investigation of death certificates for nasal cancer, but one of these men had had only one year's service with the Company.

APPENDIX II

ANALYSIS OF OCCUPATIONS OF CASES OF CARCINOMA OF LUNG AND NOSE KNOWN TO HAVE SUFFERED FROM NICKEL CARBONYL POISONING

Code No.	Date of Entry	Occupational History	Date of Nickel Carbonyl Poisoning	Date of Death	Years between Gassing and Death
(a) Cancer of Lung					
L.1	1904	Fitter	1922	1927	5
L.33	1904	C½.L2.FM1.NS32	1922	1940	18
L.71	1907	L½.C½.L½.C6.NS2½. FM1.F½.CS1.NS25.	1929	1948	19
L.111	1909	L2.CS3.FM4.NS4.FM19. F6.FM1½.M2.FM1½	1931	1953	22
L.47	1910	L½.C2.L½.C6½.L½.FM½. C½.FM1.F½.C5½. FM1½.C2.CS½.C½.CS2. FM8	1940	1944	4
L.95	1911	L2½.C½.L½.FM6.M½. NS26.CS½.M4	1925	1952	27
L.40	1913	L1½.CS5.L½.CS½.L1. CS6½.F½.L½.CS6½. NS½.FM3½	1941	1942	1
L.62	1915	CS4.L4.F2.C1.NS1.CS3. FM½.C½.NS½.F1½.C½. NS7½	1946	1947	1
L.80	1922	FM½. Out sick 1 yr. due to effects of gas. F1½.L1.CS5½.CS5. FM1½.CS9	1923	1949	26
L.37	1923	FM5.NS13	1940	1944	4
(b) Cancer of Nose					
N.31	1910	L6.CS3.L1.CS4½.F½. CS5.NS1.CS6½.FM2½	1931	1941	10
N.52	1910	Fitter—partly days but mostly shift	1944	1951	7
N.24	1911	L2.F5½.CS1.F3.L1.C1½. M1.CS8½.FM½.L1	1936	1939	3
N.59	1911	L1½.C2.FM5.M1.CS10. NS½.CS4½.NS19	1943	1956	13
N.34	1912	L1½.CS1.FM2.M1½. NS3.L½.CS1.NS8.CS½. M½.C½.L1.M1.CS5½. L½.M1.L1	1940	1943	3

C = Calciners; CS = Nickel sulphate and copper sulphate; NS = Ni sheds; L = Labourer; M = Miscellaneous; F = Furnaces; FM = Fitter's mate. (Figures denote years or part years.)

There were 10 men with lung cancer and five with nose cancer who had at some time actually suffered from nickel carbonyl poisoning. If the occupational histories of these cases are closely scrutinized it will be seen that only four were mostly engaged in nickel sheds, whilst the others had a varied occupational history.

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THE PATHOLOGY OF THE LUNGS IN FIVE NICKEL WORKERS

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This investigation is to determine whether there are any characteristic pathological changes in the lungs of men employed in nickel refining. Five patients were available for study, four of whom had developed pulmonary carcinoma. All these men had worked at the same refinery. Previous pathological reports are scanty, but a few cases have been described by Amor (1939) and by Løken (1950).

Materials and Methods

Gough-Wentworth large sections were prepared in all cases except No. 2. These sections facilitated examination, especially in judging the extent of fibrosis and the presence of cystic change. Histological sections were prepared of representative areas of the lungs, about 14 in each case. The sections were stained with haematoxylin and eosin, Van Giesen, Lendrum reticulin, and Perls's stains; in addition all were examined under polarized light.

The age, type of tumour, and source of material are shown in Table 1. Details of the manufacturing process are not given and may be seen in the preceding paper by Morgan (1958). The dates of beginning and the total duration of employment, together with the detailed occupational histories of the five cases, are shown in Table 2.

Cases 3, 4, and 5 all had one mild, transient attack of acute nickel carbonyl poisoning one year, four years, and four months respectively before death; Cases 1 and 2 had no such history.

Results

The pathological findings are summarized in Table 3 and are arbitrarily classified into three grades. A few general features may be considered before giving the details of individual cases. With the exception of Case 4 very little dust was found in these lungs on naked-eye and histological examination and in no instance did it constitute pneumoconiosis. It consisted of non-birefringent, mainly black, amorphous particles. There were also a few brown particles, 10% of which stained for iron and were thought to be haemosiderin as most of the lungs showed chronic venous congestion. None of the cases showed any evidence of silicosis. Signs of active tuberculosis were absent but Cases 1 and 4 showed healed tuberculosis in hilar glands and pleural scars. There were no demonstrable vascular changes.

Case 1.—This was a man aged 58 at death, and necropsy showed squamous carcinoma.

The right lung showed a carcinoma of the upper lobe bronchus. Both lungs showed basal bronchopneumonia, generalized oedema, and slight interstitial fibrosis. There was a slight degree of compensatory emphysema. The heart was normal. The patient died with multiple metastases.

TABLE 1

AGE, TYPE OF TUMOUR, AND SOURCE OF MATERIAL

Case No.	Age	Tumour	Source
1	58	Squamous	Necropsy
2	34	Nil	Necropsy
3	58	Alveolar cell carcinoma	Necropsy
4	60	Squamous	Pneumonectomy
5	51	Squamous	Pneumonectomy

TABLE 2

DETAILS OF PATIENTS' OCCUPATIONS IN YEARS

Case No.	Duration of Employment (years)	Date Employment Begun	Nickel Plant	Wet Treatment Plant	Gas Producers	Copper Sheds	Iron Powder Plant	Furnaces	Calciners	Unspecified General Labouring
1	33	1922	—	—	—	—	—	5	28	—
2	15	1938	2	1	—	—	2	—	—	10
3	11	1936	6	3	—	—	—	—	—	2
4	35	1913	9	—	13	2	—	—	—	11
5	17	1934	17	—	—	—	—	—	—	—

TABLE 3
HISTOLOGICAL DATA

Case No.	Tumour	Squamous Bronchial Metaplasia	Atypical Alveolar Metaplasia	Bronchiectasis	Interstitial Fibrosis	Bronchopneumonia
1	Squamous	—	—	—	+	+ + +
2	—	—	+	+ + Cystic	+	—
3	Alveolar cell carcinoma	—	Carcinoma	+ + Cystic	+ + +	+ +
4	Squamous	+	—	+	+ +	+ + +
5	Squamous	+ +	—	—	+	+

Mild + Moderate + + Severe + + +

Microscopy.—The right upper lobe bronchus was involved by a squamous carcinoma with spread into blood vessels (Fig. 1). There was a slight degree of interstitial fibrosis shown by increased amount of reticulin and little Van Giesen-positive collagen, but its nature was not specific. Bronchopneumonia was extensive. There was no evidence of bronchial metaplasia or atypical alveolar metaplasia.

Case 2.—On a man aged 34 at death necropsy showed no tumour.

The lungs showed prominent cystic change with spaces up to 3 cm. in diameter. The cysts were mainly in the posterior basal segment of both lower lobes and in the anterior and posterior segments of the right upper lobe. Bronchiectasis was also present (Fig. 2). There was a slight degree of generalized unspecific diffuse fibrosis and congestion. There was no evidence of tumour. The patient died of cor pulmonale with a hypertrophied right ventricle, probably the result of bronchiectasis.

Microscopy.—The lungs showed mild interstitial fibrosis, bronchiectasis, and bronchiolectasis producing well-marked cystic change (Fig. 3). Many alveoli were lined by single-layered epithelium with frequent multinucleated giant cells of foreign-body type (Fig. 4), designated atypical alveolar metaplasia (Jones Williams, 1957).

There was no evidence of bronchial metaplasia or recent bronchopneumonia.

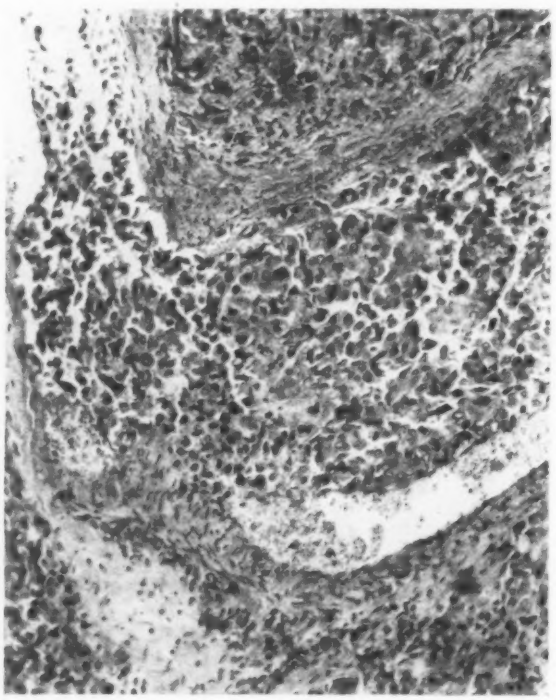

FIG. 1.—Epidermoid carcinoma with invasion of pulmonary artery. Haematoxylin and eosin, × 105.

FIG. 2.—Gough-Wentworth large section (½ natural size) of right lung of Case 2 showing cystic change and bronchiectasis.

FIG. 3.—Bronchiectasis and cystic change. Haematoxylin and eosin. × 6.

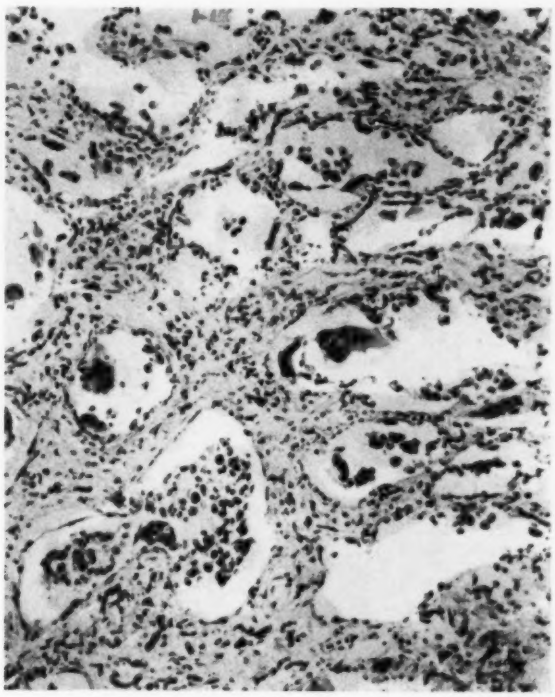

FIG. 4.—Atypical alveolar metaplasia. Haematoxylin and eosin. × 106.

Case 3.—Necropsy on this case aged 58 at death showed alveolar cell carcinoma.

Both lungs showed widespread severe diffuse interstitial fibrosis with patchy areas of consolidation. Scattered throughout both lungs were areas of " cystic change ", mainly towards the periphery, the cysts measuring up to 4 mm. diameter (Fig. 5). There was no obvious tumour of bronchi. The right ventricle was hypertrophied and the patient died with cor pulmonale with no evidence of extrapulmonary primary carcinoma.

Microscopy.—Interstitial fibrosis was severe and extensive, in many areas obliterating the air spaces. It was of recent origin, as evidenced by the presence of numerous thin-walled blood vessels. There was also intra-alveolar fibrosis resulting from organizing bronchopneumonia. The pattern of fibrosis was not specific with no tendency to nodule formation.

There was widespread bronchiolectasis and cystic change. Some cysts were lined by condensed fibrous tissue and devoid of epithelium, others were lined by bronchial epithelium. In many, the lining consisted of atypical squamoid epithelium up to 10 cells thick (Fig. 6), in some areas showing atypical mitosis (Fig. 7). The appearances favoured the diagnosis of the nodular form of alveolar cell carcinoma. The widespread epithelial metaplasia involved only peripheral air passages. Free intra-alveolar macrophages are also common, which, together with polymorphs, and intra-alveolar and interstitial fibrosis, constituted the features of an organizing bronchopneumonia.

Case 4.—A right pneumonectomy was performed on a man aged 60, and squamous carcinoma was diagnosed.

There was a 6 cm. diameter carcinoma arising at the origin of the right lower lobe bronchus and involving the hilar glands. There was a moderate degree of bronchopneumonia and basal bronchiectasis. All lobes showed moderate fibrosis. There was no evidence of emphysema or cystic change. There were a few scattered subpleural scars. The patient died nine months later with generalized carcinomatosis but no necropsy was performed.

Microscopy.—The carcinoma was of squamous type with a few keratinizing cell nests. Adjacent areas of bronchus showed squamous metaplasia (Fig. 8). The tumour was spreading outwards to adjacent fibrosed lung and also involved contiguous hilar lymph nodes.

Bronchopneumonia was widespread and most marked in the lower lobe distal to the tumour. In some areas organization was apparent (Fig. 9).

There was a moderate amount of interstitial fibrosis well marked beneath the pleura, at the margins of secondary lobules, and around bronchopulmonary trunks. It tended to be nodular with central dust-laden macrophages (Fig. 10). These features were, however, complicated by the organizing bronchopnmeuonia. There was no evidence of focal emphysema. The pleural scars consisted of dust-pigmented fibrous tissue, probably healed tuberculosis. There was no evidence of atypical alveolar metaplasia.

FIG. 5

FIG. 6

FIG. 5.—Gough-Wentworth large section (½ natural size) of left lung of Case 3 showing cystic change.

FIG. 6.—Alveolar cell carcinoma. Haematoxylin and eosin. × 150.

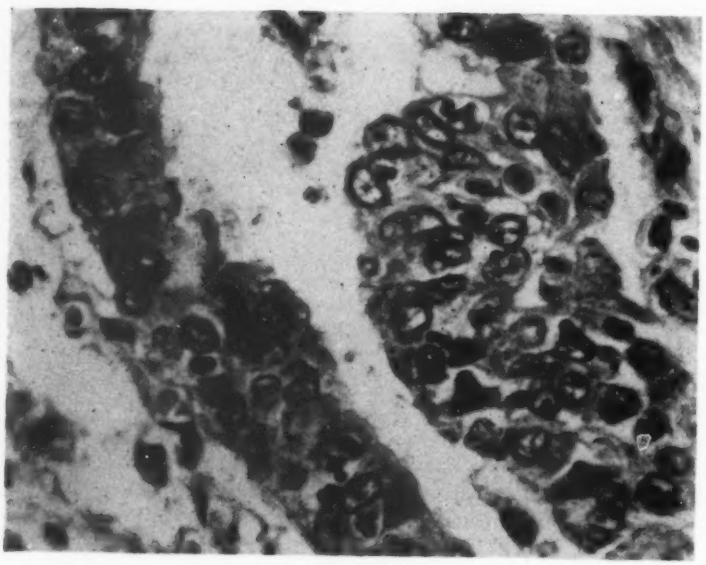

FIG. 7.—Alveolar cell carcinoma, showing mitosis. Haematoxylin and eosin, × 630.

FIG. 8

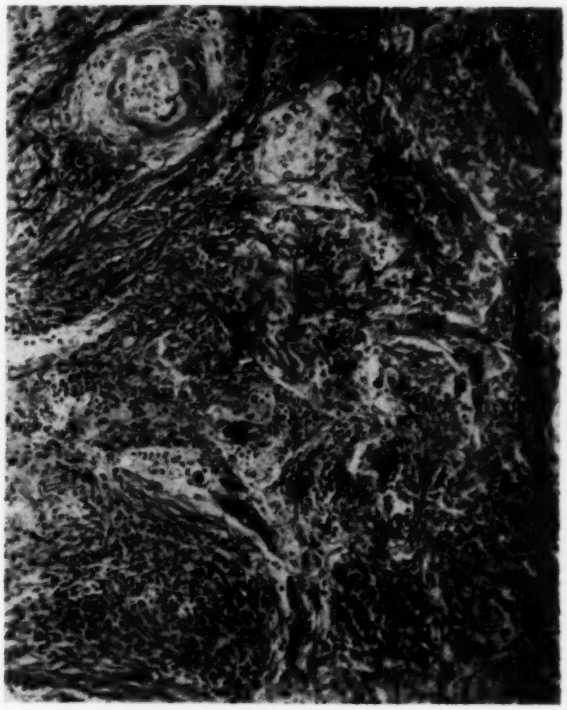

FIG. 9

FIG. 8.—Squamous carcinoma with overlying bronchial squamous metaplasia. Haematoxylin and eosin, × 85.

FIG. 9.—Section from Case 4 showing organizing bronchopneumonia with lung fibrosis. Haematoxylin and eosin, × 100.

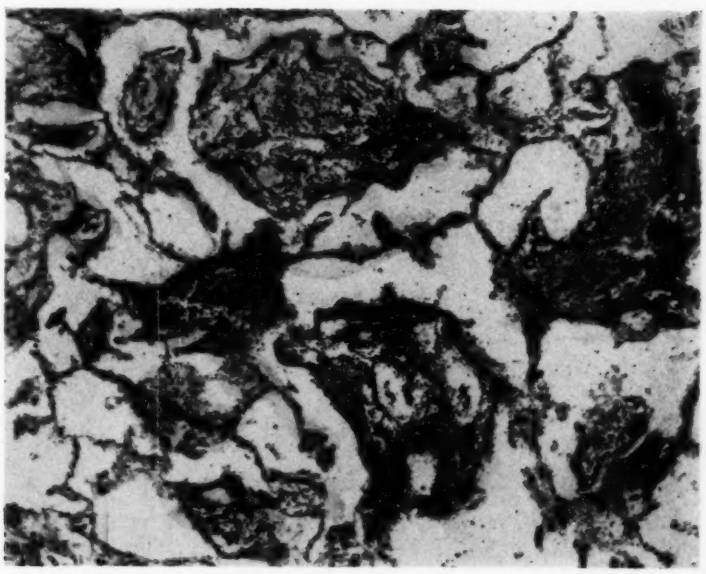

FIG. 10.—Section from Case 4 showing nodular interstitial fibrosis. Haematoxylin and eosin, × 88.

Case 5.—A man aged 57 was subjected to left pneumonectomy when squamous carcinoma was diagnosed.

There was a 2½ cm. diameter carcinoma involving the site of origin of the left upper lobe bronchus and extending to within 2 cm. of the pleura. The lung distal to this showed partial collapse and bronchopneumonia. Generalized interstitial fibrosis was minimal, "cystic change" and emphysema were absent. The patient is still alive and well 18 months after operation.

Microscopy.—The origin of the left upper lobe bronchus was partially occluded by poorly keratinizing (Grade III) squamous carcinoma. The tumour also involved the left apico-posterior bronchus. The left upper lobe showed early bronchopneumonia and partial collapse.

Squamous metaplasia was present in the left main bronchus and its divisions, both in continuity with the tumour (Fig. 11) and separate from it.

Interstitial fibrosis was slight. The alveolar lining cells were proliferating with the formation of dust-laden macrophages, but showed no indication of malignancy (Fig. 12).

Tissue Analysis

Material was available for chemical analysis in Cases 4 and 5 (Table 4). Control material consisted of pooled samples of non-industrial lungs and coal-workers' lungs, 25 of each for nickel and 10 of each for arsenic and copper. Both cases showed measurable amounts of nickel, 90 and 120 p.p.m. in dried lung, the lower limit of detection being 5 p.p.m. No arsenic could be detected in the two cases analysed, the lower limit of detection being 0·2 p.p.m. of dried lung. Nickel and arsenic were not detected in the control specimens. Copper was also estimated, being 460 and 2,810 p.p.m. in dried lungs whereas the controls showed 29 and 31 p.p.m.

TABLE 4
CHEMICAL ANALYSIS

		Ash (%)	Nickel in Dried Lung (p.p.m.)	Arsenic in Dried Lung (p.p.m.)	Copper in Dried Lung (p.p.m.)
*Controls	Coal-miners	14·95	< 5	Nil	31
	Non-miners	14·1	< 5	Nil	29
Case 4		12	90	Nil	460
„ 5		20	120	Nil	2,810

*Nickel controls were 25 coal-miners and 25 non-miners. Arsenic and copper controls were 10 coal-miners and 10 non-miners.

Discussion

These cases were the only ones available to the author and may not be representative; by chance four of the five showed pulmonary carcinoma. The case without carcinoma was included in order that

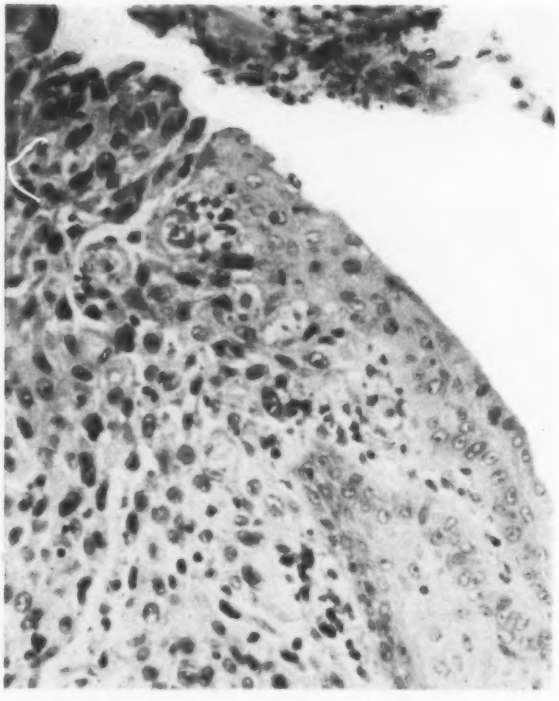

FIG. 11.—Section from Case 5, showing squamous metaplasia in continuity with squamous carcinoma. Haematoxylin and eosin. × 250.

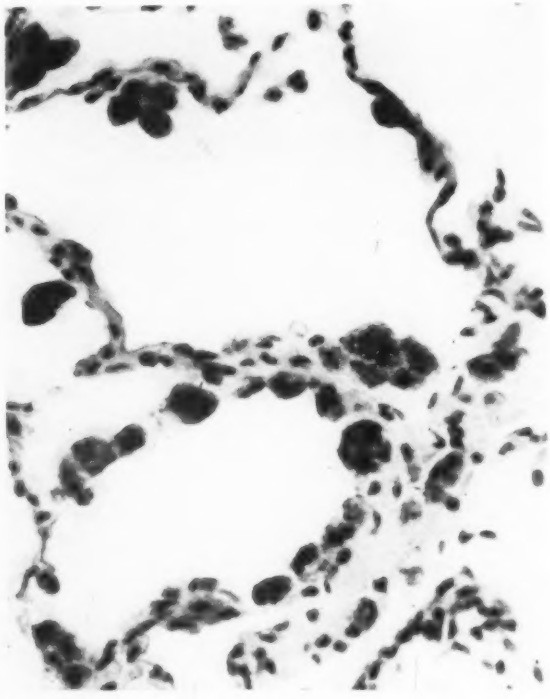

FIG. 12.—Alveolar phagocytes. Haematoxylin and eosin. × 350.

as many as possible with and without carcinoma could be examined. It is only by documenting all available cases that one can evaluate the significance of the pathological findings.

In the present series, three of the four carcinomata were squamous. Løken (1950) described three squamous carcinoma and Amor (1939) found one squamous and three anaplastic. Thus seven of the 11 reported cases are squamous. These figures are in agreement with the general opinion that the squamous variety predominates in industrially induced carcinoma. Thus Holleb and Angrist (1942) found that 60% of asbestos cancers were squamous. This finding, if confirmed in more cases, might be used to substantiate the action of an external carcinogen in nickel workers. The finding of alveolar cell carcinoma in Case 3 does not suggest the action of a carcinogen as this rare tumour has seldom been reported in industrial workers, though Jones Williams (1957) has recently reported one in an asbestos worker.

The epithelium of non-respiratory and respiratory air passages was examined for any changes which might be specific or suggest a premalignant state. Bronchial squamous metaplasia was found in two cases, both with squamous carcinoma, but they also showed evidence of chronic inflammation. As Niskanen (1949) found squamous metaplasia in 50% of lungs with chronic infection and Weller (1953) in 70% of non-industrial lung cancers, it cannot be considered specific for nickel workers nor definitely premalignant. It is an interesting supposition, however, that chronic inflammation resulting in squamous metaplasia, together with an added carcinogenic agent, might produce carcinoma. As regards respiratory air passages, Case 2 showed atypical alveolar metaplasia, but Jones Williams (1957) in a survey of 287 cases of industrial lung fibrosis from occupation, with varying incidence of lung cancer, could not relate this to the development of malignant change. It is therefore concluded that in this small series of five cases there are no diagnostic or definite premalignant epithelial changes in non-respiratory or respiratory air passages.

Two of the five cases showed honeycomb or " cystic change " which was associated with, and is probably a manifestation of, bronchiectasis and bronchiolectasis. The cysts were thick-walled which distinguishes them from emphysema. Neither of the two cases showed carcinoma of major bronchi but one showed atypical alveolar metaplasia and the other alveolar cell carcinoma; the latter also showed extensive interstitial fibrosis. The presence of " cystic change " is not diagnostic of industrial lung disease, including nickel, and may be seen in diffuse lung fibrosis from many causes, including eosinophilic granuloma (Spillane, 1952), scleroderma (Evans and Parker, 1954), and tuberculosis (Heppleston, 1956). In Case 2 it may have been congenital in origin.

Pulmonary fibrosis was present in all five cases. It involved predominantly the interstitial tissue and showed no specific localization or pattern, with the exception of Case 4 where there was a suggestion of nodularity. There was no resemblance to silicosis. Pleural thickening was inconspicuous. The fibrosis was indistinguishable from the diffuse interstitial fibrosis of industrial origin, such as asbestosis, and from that seen in non-industrial long-standing inflammation. In some cases it was associated with intra-alveolar organization, but affected primarily the alveolar walls and peribronchial tissue. There is some experimental evidence to incriminate nickel as a cause of interstitial fibrosis (Barnes and Denz, 1951), but in the present cases it is probable that the fibrosis is the result of chronic pulmonary inflammation, as four of the five showed evidence of inflammation. Only one of Løken's (1950) cases showed any fibrosis while Amor (1939) does not give any details apart from the histology of the tumours.

Carcinoma may have developed in these men irrespective of the occupation or it may have been the result of a carcinogenic agent. The statistical evidence (Doll, 1958), strongly suggests the presence of a carcinogen in this industry. He finds that lung cancer is approximately five times as frequent as in the general population, and further that the risk in men described on the death certificate as having worked directly on some part of the extraction process is about twice that for other employees. All five cases in this series can be considered as process workers. It is of interest that of the four men with carcinoma, one started work in 1922 and three after 1924. These dates are noted as the refinery underwent considerable reorganization between 1920 and 1924, which included the change from the use of crude to pure arsenic-free sulphuric acid, the wearing of masks, and general dust suppression.

There are two substances present to which these men were exposed which may be incriminated as carcinogenic agents, nickel and arsenic. Nickel is suspect both as the element and as the gas, nickel carbonyl. Hueper (1952) produced malignant tumours, predominantly sarcoma, in rats, by parenteral injection of pure nickel suspended in lanolin. Sunderman (1958) claims to have produced lung cancer in rats by nickel carbonyl inhalation. Three of the four men with carcinoma had mild attacks of acute nickel carbonyl poisoning but the interval before death is too short to agree with the long latent interval usually accepted for the induction of industrial carcinoma. This, however, does

not exclude long-continued subclinical exposure which may have been suffered by three of the four patients with carcinoma who had worked in the nickel plant for six, nine, and 17 years respectively (Table 2). Stringent precautions are, however, taken to avoid and detect gas leakages in the carbonyl process. All five cases were exposed to nickel (Table 2) which was present in the lungs of the two cases analysed (90 and 120 p.p.m. respectively) and was not detectable in 50 control cases (Table 4). This represents between twenty and a hundredfold increase, as the lower limit of detection was 5 p.p.m.

Arsenic must also be considered as it is an accepted skin carcinogen. There is no definite evidence, however, that it produces lung cancer (Saupe, 1930; Hill and Fanning, 1948; Snegireff and Lombard, 1951). Tissue for arsenic analysis was available in Cases 4 and 5, and none could be detected. It is therefore considered unlikely that arsenic was concerned with the development of carcinoma in these two cases.

In Cases 4 and 5 copper was present in amounts up to 100 times that of the controls (Table 4). While copper is not a recognized carcinogen, its presence proves the fact of metal inhalation. Together with nickel it is retained in the body, while arsenic if absorbed is probably completely excreted.

One particular carcinogen cannot be definitely incriminated and it may be that there is a combination of carcinogens. Another possibility is that the state of the patient allows a weak carcinogen or combination of carcinogens to become effectively carcinogenic. Pulmonary inflammation might fit this role as a predisposing factor, though Doll and Hill (1952) could not prove an association between previous respiratory infection and the development of carcinoma. Case and Lea (1955), from a study of war pensioners, suggest that chronic bronchitis may be associated with the development of lung cancer. There is evidence of long-standing inflammation in four of the five cases as shown by the presence of varying degrees of bronchiectasis and/or cystic change, together with interstitial fibrosis. It may be that men with chronic inflammatory changes may, in the presence of nickel, be more liable to the development of carcinoma.

The cause of death in two of the five cases was right heart failure and it is of interest that both these cases showed " cystic change " (honeycomb lung), together with interstitial fibrosis. Two patients died with multiple metastases and no evidence of cor pulmonale, while the fifth patient is alive and well 18 months after pneumonectomy.

Summary

Lungs from five men working at the same nickel refinery (nickel carbonyl process) were examined macroscopically and histologically. The length of employment ranged from 10 to 35 years. Four had developed carcinoma of the lung, three squamous and one alveolar cell. No diagnostic or premalignant epithelial changes were found.

Four cases showed evidence of long-standing inflammation, two of these showed honeycomb lung and died with cor pulmonale. All cases showed varying degrees of non-specific diffuse interstitial fibrosis, probably of infective rather than industrial origin.

Nickel and copper were present in excess in the two cases analysed, but no arsenic could be detected.

The aetiology is discussed, and, although the evidence is inconclusive, it is possible that nickel together with chronic inflammation may be the carcinogenic factor.

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References

Amor, A. J. (1939). Bericht uber den VIII internationalen Kongress fur Unfallmedizin und Berufskrankheiten, Frankfurt A.M., 1938, Vol. 2, p. 941. Thieme, Leipzig.

Barnes, J. M., and Denz, F. A. (1951). *Brit. J. industr. Med.*, **8**, 117.

Case, R. A. M., and Lea, A. J. (1955). *Brit. J. prev. soc. Med.*, **9**, 62.

Doll, R. (1958). *Brit. J. industr. Med.*, **15**.

——, and Hill, A. B. (1952). *Brit. med. J.*, **2**, 1271.

Evans, M., and Parker, R. A. (1954). *Thorax*, **9**, 154.

Heppleston, A. G. (1956). *Ibid.*, **11**, 77.

Hill, A. B., and Fanning, E. L. (1948). *Brit. J. industr. Med.*, **5**, 1.

Holleb, H. B., and Angrist, A. (1942). *Amer. J. Path.*, **18**, 123.

Hueper, W. C. (1952). *Tex. Rep. Biol. Med.*, **10**, 167.

Løken, A. C. (1950). *T. norske Laegeforen.*, **70**, 376.

Morgan, J. G. (1958). *Brit. J. industr. Med.*, **15**, 224.

Niskanen, K. O. (1949). *Acta path. microbiol. scand.*, Suppl. 80.

Saupe, E. (1930). *Arch. Gewerbepath. Gewerbehyg.*, **1**, 582.

Snegireff, L. S., and Lombard, O. M. (1951). *A.M.A. Arch. industr. Hyg.*, **4**, 199.

Spillane, J. D. (1952). *Thorax*, **7**, 134.

Sunderman, F. W. (1958). Personal communication.

Weller, R. W. (1953). *Amer. J. clin. Path.*, **23**, 768.

Williams, W. Jones (1957). *Brit. J. Cancer*, **11**, 30.

Brit. J. industr. Med., 1958, **15**, 243.

CHRONIC CHLOROFORM INTOXICATION

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Chloroform was discovered in 1831 by a French chemist, Soubeiran, and independently by the American, Samuel Guthrie of Sachett's Harbour, in the State of New York (Duncum, 1947). Soubeiran obtained impure chloroform, which he provisionally called " bichloric ether ", by distilling a mixture of chloride of lime and alcohol. Liebig, in the following year, obtained a purer chloroform, which he named " liquid chloride of carbon ", by a similar process. It was not until 1834 that Dumas succeeded in obtaining and correctly analysing pure chloroform and it was he who first gave it that name.

According to David Waldie, chemist to the Apothecaries' Company of Liverpool, " chloric ether " was first introduced into British practice as a medical agent in Liverpool in 1838 or 1839, where a prescription containing " chloric ether " as one of the ingredients was brought to the Apothecaries Hall. On looking into the matter—for the substance was unknown—he found the formula for its preparation in the United States Dispensatory.

James Young Simpson first saw ether-inhalation anaesthesia successfully practised in January, 1847, and at that time he was impressed with the idea that other therapeutic agents would be found which could be introduced into the system with equal rapidity through the channel of pulmonary absorption. In October, 1847, David Waldie directed his attention to chloroform. By November, 1847, Simpson could report that he had used chloroform as an anaesthetic in tooth-drawing, opening abscesses, for annulling the pain of dysmenorrhoea and of neuralgia, in obstetric practice, and through the kindness of Professor Miller and Mr. Duncan had tried its effects in three cases of surgical operation at the Royal Infirmary of Edinburgh.

The first death under chloroform anaesthesia occurred near Newcastle on January 28, 1848, in a healthy girl of 15 who was having a toe-nail removed. At necropsy death was ascribed to congestion of the lungs, but Snow thought that an overdose had been given resulting in paralysis of the respiratory muscles. Since this time the popularity of chloroform as an anaesthetic has waxed and waned and has often been the subject of violent controversy.

Physical Properties and Industrial Applications

Chloroform, $CHCl_3$, is a colourless, clear, very volatile sweet-tasting liquid with a characteristic odour; it has a specific gravity of 1·50 and boils at 61·2° C. The liquid is not inflammable but the vapour is capable of burning.

Commercially it is not a popular solvent but is so used in the lacquer industry, in artificial silk manufacture, in the plastics industries, as a constituent of floor polishes, for the sterilization of catgut (in which case it is usually mixed with methanol), and, to some extent as a cleaning fluid.

Toxicity

Chloroform vapour is absorbed and excreted through the respiratory tract but a little is decomposed in the organism and is present in the urine as chloride. The vapour exerts a local stimulant and irritant effect on the skin, conjunctiva, and mucous membranes of the respiratory and alimentary passages. Like other members of the group of chlorinated hydrocarbons, chloroform exerts a narcotic effect and damages the liver and kidneys, but in this respect it is considered to be of a lower order of toxicity than carbon tetrachloride (Browning, 1953). Intoxication from exposure to chlorinated hydrocarbons occurs in acute and chronic forms, and there is little doubt that certain constitutional factors render some persons more susceptible than others (Hamilton and Hardy, 1949).

The casualties during and after chloroform anaesthesia have been well described. Death during anaesthesia is the result of cardiac and respiratory failure, whereas damage to the liver and kidneys characterizes delayed poisoning. There is almost a complete lack of information on acute and chronic intoxication from exposure to chloroform in industry.

Moore (1955), working in an industry which

manufactures chloroform, stated that he knew of one employee who developed acute narcotic symptoms and this resulted from carelessness during maintenance operations. He added that there is little danger from the small concentrations of chloroform that occur in the atmosphere when the plant is working properly. Browning (1953, 1955) quotes two instances of poisoning from exposure to low concentrations of chloroform. In the first case several women were employed in sterilizing catgut using chloroform in a workshop where the ventilation was inadequate, consisting of two small roof windows and a fan which had not been used for over a year. Only one of the girls made any complaint of ill-health; she said she felt dazed and drowsy. In the second case a chemist's apprentice, engaged in decanting chloroform, complained of vertigo, headache, and an inability to stand upright. Lehmann and Flury (1943) write : " Industrial poisonings, in contrast to the numerous medical experiences with chloroform, are very rare." They add that working with chloroform leads to an increased flow of saliva and tears and that dizziness, stupor, and disturbances of equilibrium are observed, but they do not refer to any specific instances of intoxication.

Heilbrunn, Liebert, and Szanto (1945) describe the clinical effects of chloroform addiction in 29 authentic cases which they were able to collect from the literature since 1830. The chloroform was usually consumed by inhalation, but occasionally supplemented by oral administration, in doses ranging from a few drops to 1,000 ml. in 24 hours, and over a period of time of from three to 40 years. The effects described varied from negligible to " wrecking of the physical and mental energy of the patient". Some common symptoms and clinical signs were irritability, anxiety, periodic depression, delusions, hallucinations, paraesthesiae, hand tremors, and emaciation. The chronic effects of addiction to chloroform bear some resemblance to those of chronic alcoholism.

In bygone years anaesthetists must have had many hours of exposure to chloroform in their working atmosphere. Dr. H. G. Epstein, of the Nuffield Department of Anaesthetics, Oxford, however, informed us (1955) that he could not trace any relevant article in the literature on anaesthetics available to him. He considered that the risk of exposure to chloroform vapour in operation theatres has always been much less than that to ether vapour, as chloroform has been given in many cases from small inhalers which must have greatly reduced the contamination of the ambient air.

Description of the Processes

The investigation to be described was the outcome of an enquiry to our Laboratories from a firm employing some 1,500 workers, of whom 75% were women. A full-time nurse is employed but there is no medical officer.

One of their products is a well-known type of medicinal lozenge, and difficulties had arisen owing to the use of chloroform as one of the main ingredients. The manufacturing process consists of two operations, mixing and cutting, which are carried out by different groups of employees in two separate workrooms. In the mixing room, the ingredients are placed in a mechanically operated mixing drum, which is kept closed during the mixing period of about 20 minutes. The moist paste is then discharged into an open metal tray, covered with a damp cloth, and removed to the cutting room. The emptying of the mixer is shown in Fig. 1. In the cutting room the mixture is loaded by hand into a hopper, from which it is extruded in sheets. These sheets are then mechanically cut into lozenge form, dusted with sugar, stored for 24 to 48 hours to harden, and subsequently packed. Both cutting and hardening take place in the same room, which is kept at a temperature of 78° F. or more, and in which the windows are kept shut. A general view of the room is shown in Fig. 2.

In 1947 mechanization of the cutting operation increased the capacity of the plant from 3 cwt. to 17 cwt. per day, although the average seasonal output was only 9 cwt. per day. In 1950 the operators began to complain of the vapours which were given off from the paste during the cutting and hardening processes, and it was alleged that unpleasant symptoms were being experienced. These were largely subjective in nature, and were not regarded seriously at first, particularly as it was suspected that a temporary assistant in this department, who had had some previous medical training, might have been partly responsible for the suggestion that the " fumes " could cause symptoms. However, the complaints continued, and a system of part-time working was instituted and some improved ventilation provided. These measures, however, did not solve the problem and eventually the whole group of operators refused to continue working on this particular process. In 1954 a new team of operators was engaged, and in 1955 a system of exhaust ventilation was installed. Since this time work has continued without interruption, but the management was anxious to confirm the effectiveness of the exhaust ventilation system. We were therefore asked to assess the concentrations of chloroform in the air of the cutting room with the plant in operation, but we eventually carried out a much more detailed investigation than had originally been envisaged.

FIG. 1.—Emptying of mixer.

FIG. 2.—General view of cutting room.

Environmental Investigation and Results

In the first series of environmental measurements, the normal methods of production were in progress. In the mixing room a continuous air sample was taken at the breathing zone of the operator during the mixing period of 20 minutes, the sample being drawn at 1 litre per minute through two U-tubes in series, each containing dried silica gel. In addition a large " grab " sample of approximately 6 litres of air was taken at the breathing zone of the operator at the time of emptying of the mixer, when a peak concentration was expected. Air samples of 30 minutes' duration were also taken simultaneously at the breathing zones of the operators at three positions in the cutting room during two periods of production on the same day; the exhaust ventilation was then in operation, but windows were kept closed. These air samples were subsequently analysed for chloroform by a modification of the Volhard method (Elkins, 1950; Hickish, Smith, and Bedford, 1956).

We wished to know the concentrations of chloroform to which the original workers in the cutting room had been exposed, *i.e.*, after the process had been mechanized but before the installation of exhaust ventilation, and an attempt was made to simulate the original conditions so far as was practicable. The doors and windows of the cutting room were kept closed and the exhaust ventilation was not in operation; it was considered by those who had seen the previous methods of working that a reasonable simulation was achieved in this way. There was general agreement that the concentrations occurring during the simulated operation were certainly not in excess of those previously experienced. The air samples were again taken in positions corresponding to those in the first series of measurements in the cutting room, and also in the centre of the room.

The results of the air analyses are given in Table 1.

TABLE 1

CONCENTRATIONS OF CHLOROFORM IN AIR OF MIXING AND CUTTING ROOMS OF A CONFECTIONERY FACTORY

Operation	Chloroform Concentration (p.p.m.)*		
	Period 1	Period 2	Period 3
Mixing room during normal operation			
Continuous sample during mixing period	128	—	—
Grab sample during emptying period	1,163	—	—
Cutting room during normal operating conditions			
Feeding operation	71	57	—
Dusting operation	35	31	—
Removing trays	23	29	—
Cutting room during simulation of original conditions			
Feeding operation	219	237	161
Dusting operation	110	158	155
Removing trays	77	92	—
General atmosphere at centre of room	82	98	—

*The present value of the maximum allowable concentration (M.A.C.) for chloroform has been set by the American Conference of Governmental Industrial Hygienists at 100 p.p.m. and by Imperial Chemical Industries Ltd. at 50 p.p.m.

The concentration of 1,163 p.p.m. occurs only for a period of one and a half to two minutes during the emptying of the mixer, and contributes largely to the average concentration of 128 p.p.m. Elimination of this peak, *e.g.*, by the application of exhaust ventilation during emptying, would reduce the average exposure during the whole mixing operation to the order of between 10 and 40 p.p.m. The mixing operation is carried out not more than four times a day and thus the total time occupied on this operation is about two hours a day.

Clinical Investigation and Results

The employees who refused to continue working in the lozenge department are hereafter termed " long-service operators " and those employees who replaced them, " short-service operators ". Twenty-two women (eight long-service operators, nine short-service operators, five controls) were interviewed and given a comprehensive medical examination; in addition four employees (two female and one male long-service operators, and one female short-service operator) were interviewed but not examined. The interviews were carried out some months before the medical examinations, as there was considerable resistance to examination from the long-service operators, but eventually all but three agreed to cooperate. In the interim period a short-service operator who had been interviewed left the firm. The male long-service operator was engaged on the mixer. Eight female employees matched for age and length of employment in the firm with the long-service operators were selected as controls from other departments, but due to various reasons only five of these were available for interview and medical examination. The age distribution of the employees examined and their length of exposure to chloroform are given in Table 2.

TABLE 2

AGE AND LENGTH OF EXPOSURE TO CHLOROFORM OF LONG-SERVICE AND SHORT-SERVICE FEMALE OPERATORS AND CONTROLS

Group	Number	Age (years)		Length of Exposure	
		Range	Mean	Range	Mean
Long-service	8	40 to 60	50·5	3–10 years	5·4* years
Short-service	9	34 to 51	42·9	10–24 months	15† months
Controls	5	47 to 58	51·4	—	—

*Four subjects worked full time, and four worked half time.
†One subject worked full time, and eight worked half time.

Because the long-service operators had been exposed to chloroform for many years the possibility that they might have sustained liver damage had to be considered. The thymol turbidity, serum bilirubin, and urine urobilinogen tests were selected from the usual battery of liver function tests and performed on the 22 employees previously examined. Under different circumstances we would have carried out an excretion test; however, liver function tests, even if normal, do not exclude minor liver damage and the final answer can only be given by liver biopsy. The latter test is certainly not one which would be welcomed in a factory survey.

Symptomatology

Long-service Operators.—(This group includes the three employees not examined.)

All of these employees except one were subject to the symptoms described below, in greater or lesser degree, when they were working in the lozenge department. For purposes of easy description, the symptoms are classified under the following headings:

General.—Lassitude at the end of the day and a desire to sleep: some employees reported that when they arrived home they would fall asleep in a chair, and all the employees stated that at times they were unable to concentrate on household duties.

Alimentary.—Flatulence, a " bubbling feeling " in the abdomen, a " tight feeling in the chest ", a feeling as of a " ball in the upper part of the stomach ", a feeling that " the stomach was distended ", nausea, loss of appetite, water brash, dry mouth, thirst, a tendency to be drinking all the time.

Urinary.—Frequency of micturition and scalding micturition.

Mental.—A feeling of being dazed, lack of con-

centration, " slowness in grasping things ", " slow witted ", depression, and irritability. The supervisor reported that on occasions her employees " got hysterical and had a feeling of wanting to giggle all the time ".

All the symptoms described above could be present at work but were usually worse in the evening at home and often persisted to some extent during the weekend. One of the long-service operators did not complain of any symptoms; she was an epileptic and had been on sedative therapy for many years. No employee gave a history which suggested a previous attack of jaundice. An interesting observation made by all these employees was that since leaving employment in the lozenge department, even a short exposure to the smell of " chlorodyne " (the name given to the odour by the employees) produced nausea and a " feeling of the stomach turning over ". During the course of one of our many discussions with management the statement was made to us that occasionally some of these employees had been noticed staggering about at work.

Short-service Operators.—All but two of these employees complained of symptoms. Five reported a dryness of the mouth and throat at work, two were subject to lassitude in the evening, and the operator handling the feeder stated that she was subject to attacks of flatulence and lassitude during her working hours. Two other operators had been as severely affected as the long-service operators. One was not examined because, as mentioned earlier, she left the firm; the other gave a long and complicated history of neurotic illness, so that it was difficult, in her case, to assess the importance of environmental factors.

Controls.—None of these employees complained of symptoms similar to those which have been described above.

The findings on medical examination are summarized in Table 3; no organic lesion, for instance, enlarged liver, was discovered which could be attributed to exposure to chloroform. The results and analysis of the liver function tests are shown in Tables 4 and 5.

The only difference of statistical significance ($P = 0.05$) is that between the means of thymol turbidity for the long-service and short-service groups.

TABLE 3

PHYSICAL DEFECTS DISCOVERED AT MEDICAL EXAMINATION

Long-service Operators		Short-service Operators		Controls	
Case No.		Case No.		Case No.	
1	Epilepsy	1	Chronic otitis media (L.)	1	Nil
2	Urticarial rash	2	Thyroid adenoma (asymptomatic)	2	Nil
3	B.P. 180/100 Age 46	3	Nil	3	Thyroid adenoma (asymptomatic)
4	Nil	4	Hypertension with symptoms (B.P. 250/140) Age 45	4	Migraine
5	Nil	5	Nil	5	Chronic bronchitis, peptic ulcer. B.P. 180/110 Age 58
6	Nil	6	Nil		
7	Nil	7	Osteoarthritis of knee joints and cervical spine		
8	Nil	8	Nil		
		9	Nil		

TABLE 4

RESULTS OF LIVER FUNCTION TESTS

Subject		Age	Urine		Blood			
			Urobilin	Urobilinogen	Thymol Turbidity (Normal Value 0–5 units)	Thymol Flocculation (0–1)	Van den Bergh (Direct)	Serum Bilirubin (Normal Value 0·1–0·8mg./100ml.)
Long-service operators	1	60	Negative	Negative	1	—	Negative	0·3
	2	57	,,	,,	2	—	,,	0·3
	3	53	,,	,,	1	—	,,	0·5
	4	40	,,	Trace	2	—	,,	0·3
	5	48	,,	Negative	1	—	,,	0·2
	6	46	,,	,,	3	—	,,	0·4
	7	48	,,	,,	1	—	,,	0·3
	8	52	,,	,,	1	—	,,	0·3
Short-service operators	1	34	Negative	Negative	3	—	Negative	0·4
	2	35	,,	,,	2	—	,,	0·2
	3	51	,,	Trace	4	—	,,	0·2
	4	41	,,	,,	3	—	,,	0·3
	5	51	,,	Negative	3	—	,,	0·2
	6	45	,,	,,	1	—	,,	0·3
	7	36	,,	,,	1	—	,,	0·2
	8	42	,,	Trace	3	—	,,	0·3
	9	51	,,	Negative	4	—	,,	0·1
Controls	1	48	Negative	Negative	3	—	Negative	0·1
	2	50	,,	,,	5	Incomplete	,,	0·3
	3	47	,,	,,	1	—	,,	0·3
	4	54	,,	,,	1	—	,,	0·4
	5	58	,,	,,	2	—	,,	0·2

TABLE 5
STATISTICAL ANALYSIS OF LIVER FUNCTION TESTS

Group	Serum Bilirubin (mg./100 ml.)		Thymol Turbidity (units)	
	Range	Mean	Range	Mean
Long-service (8) ..	0·2–0·5	0·325	1–3	1·5
Short-service (9) ..	0·1–0·4	0·244	1–4	2·66
Control (5)	0·1–0·4	0·260	1–5	2·40

Discussion

There is only one difference in the results of the liver function tests between long-service operators, short-service operators, and controls which is of statistical significance, and this difference is small and difficult to interpret. In view of the fact that all the results are within the normal range for these liver function tests it is concluded that there is no evidence from these tests of damage to the liver. It is unlikely that the operators from the lozenge department have suffered permanent liver damage but only liver biopsies could be the final arbiter in this judgment. Stewart and Witts (1944), discussing carbon tetrachloride, state that " to bring about permanent liver damage there must be exposure sufficient to produce an immediate toxic effect and the dose must be repeated at short intervals ", and " if each dose of carbon tetrachloride is too small to produce changes in the liver, no matter how frequently it is repeated, there will be no hepatic damage ". It is well known from animal studies that liver damage is a reversible process, that the liver has remarkable powers of repair, and that after injury it can revert to its normal state (Goldblatt and Goldblatt, 1956).

As might have been expected, there is a considerable resemblance between the clinical effects described in this paper and those recorded by Stewart and Witts (1944) in their study of chronic carbon tetrachloride intoxication. They were not able to obtain any useful figures for air concentrations of carbon tetrachloride but they state that " the characteristic symptoms of exposure to sublethal concentrations of carbon tetrachloride vapour are gastro-intestinal stress and mental hebetude ", and elsewhere:

> " It is therefore suggested that mental hebetude is due to the effect of carbon tetrachloride on the cerebral cortex, and the gastro-intestinal symptoms are due to stimulation of the parasympathetic or inhibition of the sympathetic centres in the hypothalamus. Both effects can be paralleled by the known actions of chloroform."

In their investigation Stewart and Witts noted that some employees acquired " such a distaste for the smell of carbon tetrachloride that they experienced attacks of vomiting in circumstances which had previously had no effect". The long-service operators in our study, with the one exception, an epileptic on sedative therapy, had all become hypersensitive to the smell of chloroform. Obviously such a phenomenon could be regarded as " psychological " or even as plain malingering, but this is not the opinion of Stewart and Witts who considered that it was necessary to look beyond the liver and kidneys for an explanation of the mechanism of chronic carbon tetrachloride intoxication. In their opinion the above symptoms " bear a strong resemblance to post-anaesthetic sickness and recall the chemical relationship between carbon tetrachloride (CCl_4), chloroform ($CHCl_3$), and ethyl chloride (C_2H_5Cl) ". Cushny (1941) considers that vomiting after anaesthesia may arise as a local irritant effect and from central origin, and adds that it can occur from odour and taste " more especially in people who have been anaesthetized previously and have unpleasant associations with the odour ".

Our long-service operators complained of urinary symptoms and it is difficult to explain these on the basis of a local stimulant and irritant effect on the bladder. Might a possible explanation be that of an action through the hypothalamus producing parasympathetic stimulation of the bladder ?

As previously stated, the maximum allowable concentration (M.A.C.) for chloroform has been set by the American Conference of Governmental Industrial Hygienists at a level of 100 p.p.m. In discussing this value Warren Cook (1945) states:

> " Since there is no published work on prolonged exposures of animals under experimental conditions or of humans in industrial occupations to known low concentrations of chloroform, a value of 100 p.p.m. is generally accepted on the basis of analogy with carbon tetrachloride. The value as given should be further substantiated and there should be close medical observation of any group of workers exposed to chloroform concentrations approximating 100 p.p.m. As is the case with carbon tetrachloride, it would be wise to retain exposures to less than 50 p.p.m. until more data are available."

This view coincides with the recommendation by Imperial Chemical Industries Ltd. that the concentration of chloroform in the working atmosphere should not exceed 50 p.p.m., a value which has been set in the light of unpublished results of animal experimentation (Goldblatt, 1956). The fact that the long-service operators who had apparently been exposed to concentrations ranging from 77 to 237 p.p.m. exhibited symptoms provides confirmation that the M.A.C. should not exceed 100 p.p.m. The short-service operators who, with one exception, were working four hours daily, were exposed to concentrations of from 21 to 71 p.p.m. They also complained of symptoms, but our impression was that dryness of the mouth and throat, at least, could

be attributable to the unsatisfactory thermal conditions. However, the employee operating the feeder who also worked four hours daily reported symptoms similar to, though less severe than, those experienced by the long-service operators. She was exposed to the highest concentrations of 56 to 71 p.p.m.

At the end of our investigations we advised the firm to make certain alterations in the exhaust ventilation system of the cutting room, to institute periodic medical supervision of the operatives at risk, and to substitute some other substance for chloroform in their product. If this last item of advice was not a feasible proposition, then the concentrations of chloroform in the working atmosphere should not be allowed to exceed 50 p.p.m. In our opinion this permissible limit offers a more reasonable factor of safety, in the light of the evidence which we accumulated.

Summary

A brief historical note on chloroform is followed by a general review of its characteristics, industrial applications, and toxicity.

An environmental and clinical investigation has been carried out in a confectionery firm where employees, engaged in the manufacture of a medicinal product, were exposed to chloroform vapour. In a group of 10 employees, believed to have been exposed to concentrations ranging from 77 to 237 p.p.m., nine complained of severe symptoms. No evidence of liver damage was found in the eight who submitted themselves to medical examination and liver function tests.

In another group of 10 employees, exposed to concentrations ranging from 22 to 71 p.p.m., eight complained of less severe symptoms. No evidence of liver damage was discovered in the nine who submitted themselves to medical examination and liver function tests.

The symptomatology is discussed in relation to that experienced by persons exposed to low concentrations of carbon tetrachloride.

The maximum allowable concentration of 100 p.p.m. recommended by the American Conference of Governmental Industrial Hygienists is considered to be too high, and the evidence from the present investigation supports the value of 50 p.p.m. suggested by Imperial Chemical Industries Ltd.

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REFERENCES

Browning, E. (1953). *Rep. industr. Hlth Res. Bd (Lond.)*, No. 80 (rev. ed.), pp. 128 and 136.
—— (1955). Personal communication.
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REFERENCES

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Brit. J. industr. Med., 1958, **15**, 250.

COUNTING ERRORS DUE TO OVERLAPPING PARTICLES IN THERMAL PRECIPITATOR SAMPLES

BY

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A sample of airborne dust taken with the standard thermal precipitator consists of two deposits about 1 cm. long and 1 mm. wide obtained from either side of the heated wire (Green and Watson, 1935). These deposits are examined under a microscope and a count is made across each of them to estimate the number of particles collected.

The particles commonly have an irregular shape and some consist of several smaller particles clumped together. It is usually assumed that these clumps or "aggregates" of particles were present when the dust was airborne and they are therefore counted as single particles. During the sampling some of the particles are deposited so that they cover or overlap others already deposited, producing spurious aggregates. When examined under the microscope this type of aggregate cannot normally be distinguished from one which existed as such in the air and these aggregates are also counted as single particles. Consequently the airborne dust concentration is underestimated. In the many previous tests of the thermal precipitator the magnitude of this error does not seem to have been investigated.

If two instruments are operated close together and the volume of air sampled by one is greater than the volume of air sampled by the other, the deposits obtained with one instrument will be more crowded than the deposits obtained with the other and hence the airborne dust concentrations estimated from the two instruments will be different. Therefore it was thought that by comparing the results from pairs of samples taken in this way, with very different volumes, it would be possible to estimate the magnitude of the bias due to overcrowding that normally occurs.

As air is drawn through the thermal precipitator at a constant flow rate the volume of air sampled can be varied by altering sampling time.

Experimental Procedure

Two thermal precipitators were set up side by side underground in a colliery. Pairs of samples were then taken in which one of the instruments sampled for five times as long as the other. Each short-period sample was taken during the middle of the corresponding sample taken by the long-period instrument. One hundred and twenty-five such pairs of samples were taken in different places in the colliery so as to include a wide variety of dust concentrations.

All the samples were then counted using a 2 mm. oil immersion objective, counting all visible particles. Then all the samples were re-counted using a 4 mm. objective, restricting the count to those particles which were between 1 and 5 microns in diameter. In both cases any aggregate consisting of particles which overlapped one another was counted as one particle.

In this way 250 pairs of results were obtained which, in the absence of overlap errors, would be expected to agree after allowing for the different volumes of the samples.

To check that the two instruments gave the same result when sampling identically, 15 pairs of samples were taken in which both instruments sampled for 10 to 15 minutes and 15 pairs of samples were also taken in which both instruments sampled for two to three minutes.

Finally a detailed size analysis was done on a number of the less dense samples selected at random. The object of this was to compare the amount of overlapping found with the amount expected from theoretical considerations. This can be calculated from the size distribution by making certain simplifying assumptions about the way the dust deposits.

Results

A comparison of the mean counts of corresponding short- and long-period samples is given in Fig. 1. The short-period counts were grouped and averaged and the corresponding long-period means calculated. In the absence of overlap errors the counts from the long-period samples would be expected to be roughly five times those of the short-period samples. This is shown by the straight line. In fact, the counts from the long-period samples were only about three times the count from the short-period samples, suggesting that a considerable amount of overlapping occurred

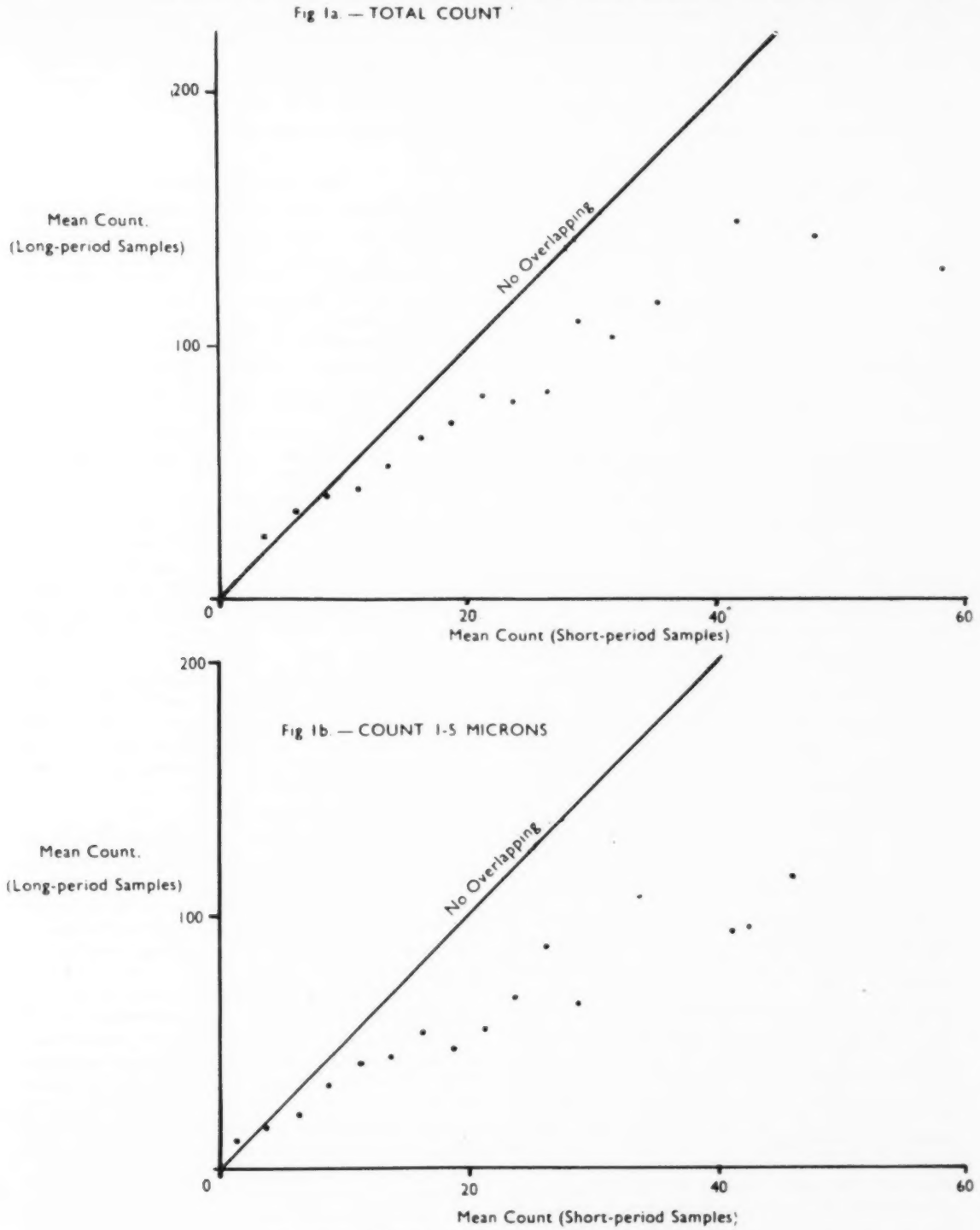

FIG. 1.—Comparison of short- and long-period samples (20μ traverse).

in the denser samples. This result was not unexpected since, when counting the densest samples, many long chains of overlapping particles could be seen.

A summary of the size distribution of the dust is given in Table 1. The mean projected area of the particles was 18·6 sq. microns.

TABLE 1
SIZE DISTRIBUTION OF THE DUST

Size Range (μ)	% of Particles
< 0·5	22
0·5–1	19
1–2	21
2–3	14
3–4	9
4–5	5
5–10	7
10–20	2
20–50	1
< 50	0
Total ..	100

The agreement between the two instruments when sampling identically is shown in Table 2. There is no suggestion from these results that one instrument was biased relative to the other.

TABLE 2
MEAN COUNTS FROM TWO THERMAL PRECIPITATORS SAMPLING IDENTICALLY
(20 *micron traverse*)

Period Sampling	Size Range	T.P.	Number of Samples	Mean Count
Long	Total	1	15	60·5
		2	15	62·9
	1 to 5μ	1	15	33·0
		2	15	32·6
Short	Total	1	15	41·7
		2	15	41·9
	1 to 5μ	1	15	17·0
		2	15	15·8

Another possible source of bias was the extraneous contamination on the cover glasses. This might have affected the counts from the long- and short-period samples equally. To check this point counts were made on every cover glass at points a few millimetres from the deposits. These counts were made over a traverse length of 2 mm., the maximum traverse length normally used when counting across a deposit. The counts were made using a 2 mm. objective and all visible particles were counted. The mean number counted on the cover glasses carrying the short period samples was 1·3 particles per traverse 20 microns wide, and the mean number on the cover glasses carrying the long-period samples was 1·7 particles per traverse 20 microns wide. The contamination tended to be less on the cover glasses carrying the less dense samples. Thus the effect of contamination on the comparisons is likely to have been slight. In particular in the comparisons made at the higher densities these results suggest that the effect of the contamination was negligible.

Analysis of the Results

The analysis of the results is complicated by the fact that the counts from both the long-period samples and the short-period samples are affected by the overlap error, although to different extents.

The effect of overlapping is that the number of particles counted in unit area is less than the number actually deposited. With deposits of increasing density the number counted on each deposit would eventually cease to rise and would actually begin to fall as the gaps between the particles become fewer until finally all the particles overlap one another. That is, in the limit the number counted per traverse tends to zero. If, therefore, the number deposited in unit area could be plotted against the number counted, a curve of the form shown in Fig. 2 would be obtained. Initially the number counted would be nearly equal to the number deposited, shown by the straight line. The number counted per traverse would rise to a maximum and then fall off, eventually tending to zero as the number deposited became very large.

Apart from these general properties the exact mathematical form of the relationship is not known. Curves relating the number counted (y) to the number deposited (x) were therefore fitted to the data by finding those which would account for the observed differences when using the equation,

$$y = xe^{-ax},$$

where " a " is a constant.

This has the following advantages: (1) It has the general properties described above. (2) It is simple to fit to the data. (3) It is similar in form at low densities to the approximations suggested by Irwin, Armitage, and Davies (1949), Armitage (1949), and Mack (1956).

The ratio of the volumes used for the long- and short-period samples varied between 4·74 and 5·57 for different pairs of samples. The mean count from each long-period sample was multiplied by the ratio of the volumes of air actually sampled by the short- and long-period instruments, so as to make it comparable with the mean count from the short-period sample. A comparison of the results from the individual pairs of samples is given in Fig. 3 where the count from the short-period sample is plotted against the difference between it and the comparable count from the long-period sample. In the absence

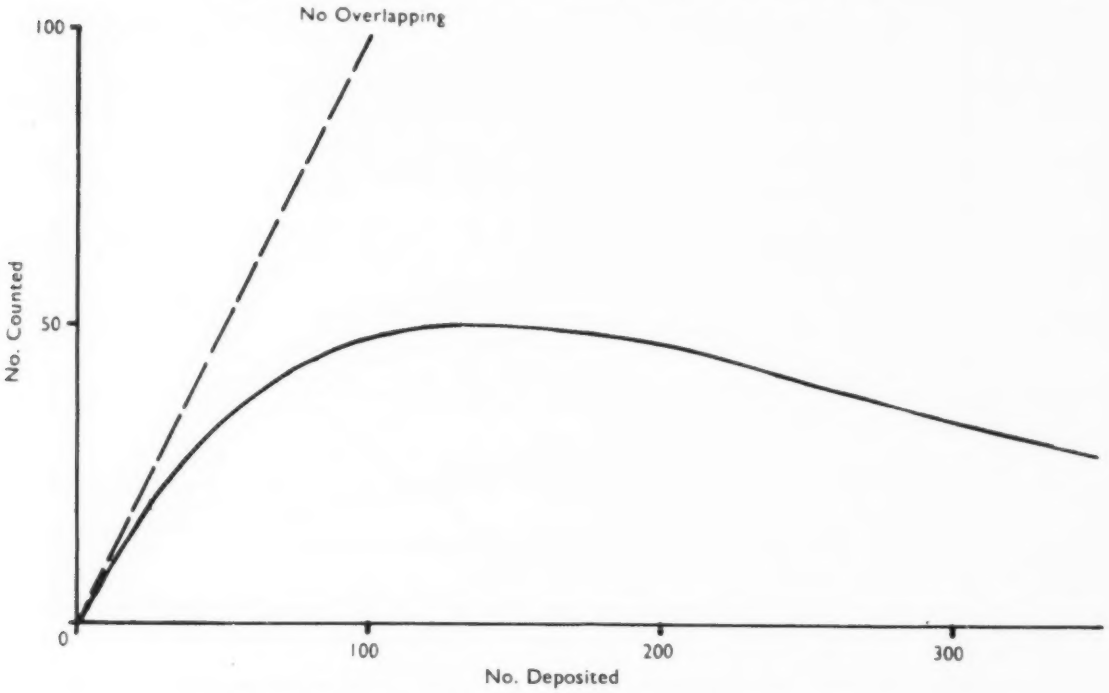

FIG. 2.—The number deposited in unit area and the corresponding number counted.

of overlapping we would expect the difference between the two counts to vary around zero. It can be seen that in practice the difference increases with the density of the samples, as we would expect if overlapping were taking place. Fig. 3 also shows that the fitted curves describe the relationship adequately.

The constant "a" would be expected to depend on the size distribution of the airborne dust. The finer the airborne dust, the smaller will be the magnitude of "a", the more nearly will the number counted (y) be equal to the number counted (x) and the less will be the effect of overlapping on the number count.

From every pair of results it was possible to calculate a value for "a". It was expected that the counts obtained would be more variable than the size distribution, with the result that the variability of the values for "a" obtained from the counts would fall off roughly as the inverse square of the count. This was found to be the case. The individual values of "a", for the total count and the count from 1 to 5 microns, were therefore weighted by the square of the count in deriving mean values.

Because of the high variability of the calculated value for "a" at very low densities, mentioned above, and because these counts tend to be unreliable owing to contamination and the difficulty of focusing on sparse deposits, in calculating the mean value for "a" results were excluded where the total number counted on the short-period sample was less than 8 particles per traverse.

The mean value for "a" was 0·0026 for the total number count and 0·0048 for the count 1-5 microns. The difference between the number deposited and the number counted can be estimated from these results. The number counted is less than the number deposited by an amount which increases with the density of the deposit. The corresponding correction to be added to the number counted is given in Fig. 4. The correction is expressed as a percentage of the number count.

Discussion

Green and Watson (1935) in their original description of the thermal precipitator recommended a density of 62 particles for a traverse 22·2 microns wide but thought counting was possible when the deposit was one-fifth or about 20 times as dense. They said: "At the higher limit aggregation and superimposition of particles may become serious obstacles to accurate counting." The Transvaal Chamber of Mines (1947), when referring to the counting of particles in a traverse 8·5 to 8·7 microns

Fig 3a.—TOTAL COUNT

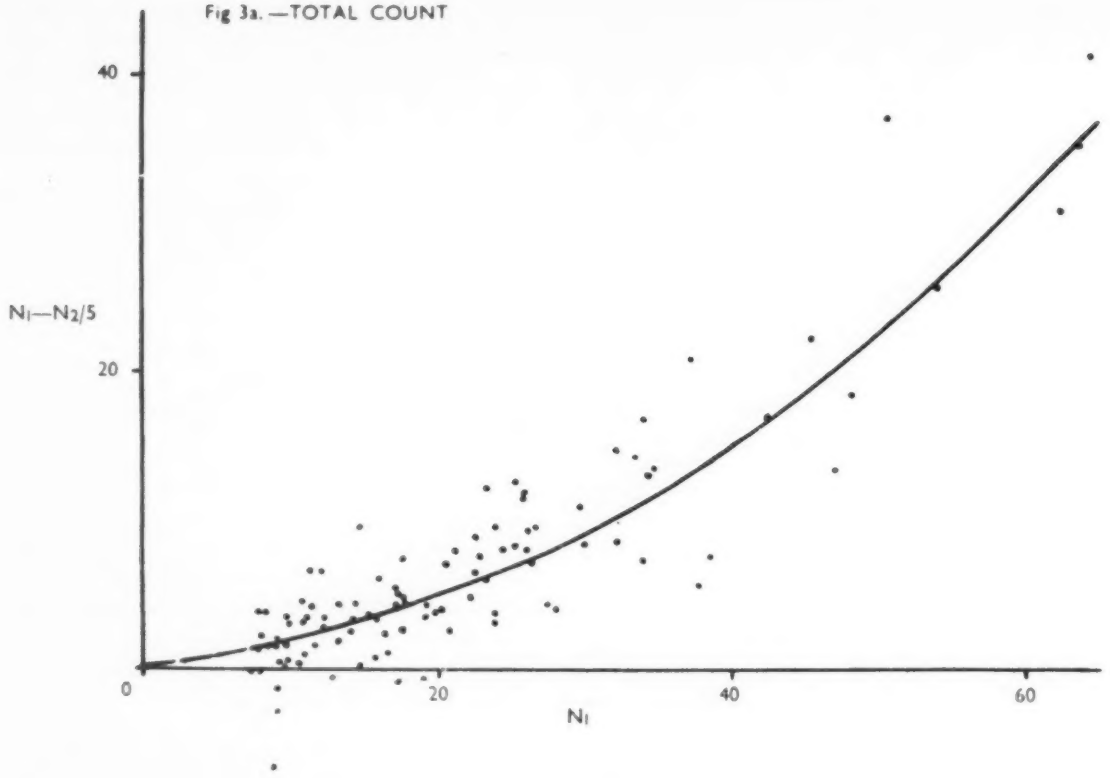

Fig 3b.—COUNT 1-5 MICRONS

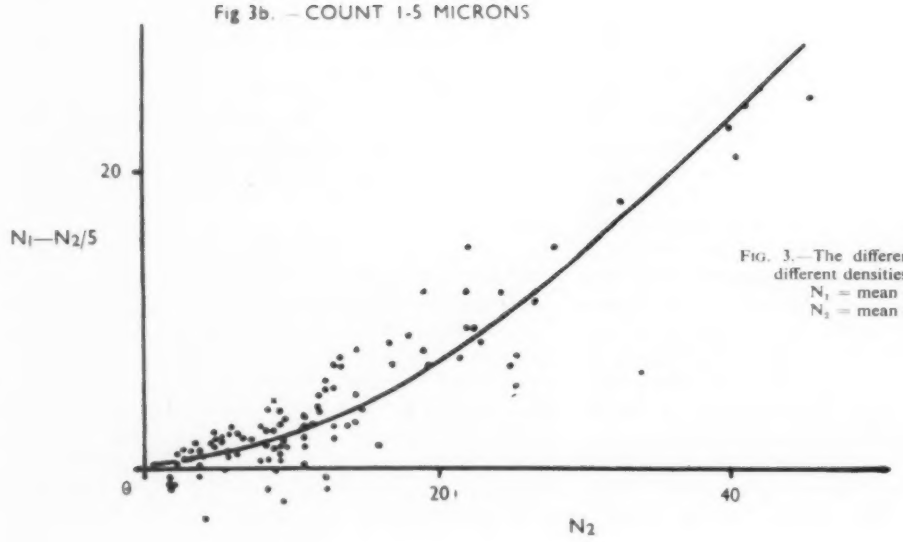

FIG. 3.—The difference between the counts at different densities (20μ traverse).
N_1 = mean count, short-period sample
N_2 = mean count, long-period sample

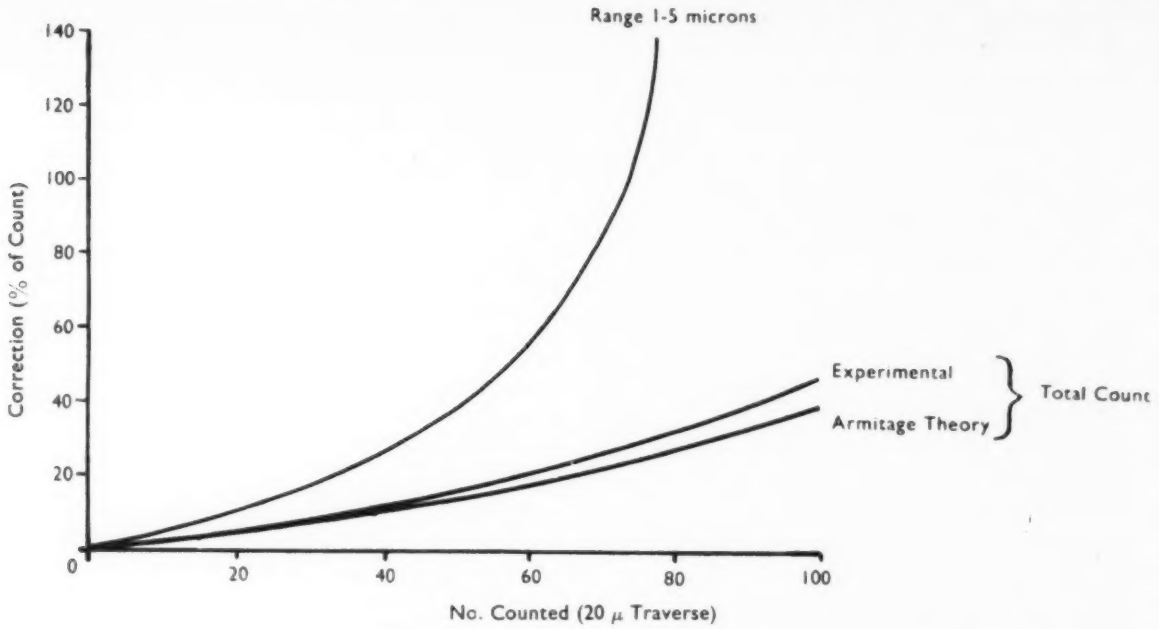

FIG. 4.—The correction to be added to the count.

wide, say, " If the record is too thick, crowding of the particles causes inaccuracy and counting becomes difficult and tiring. . . " and " the density should not be higher than about 300 particles per strip ". They say later, " A density of about 100 particles per strip is most satisfactory in practice and, so far as possible, sampling must be arranged with this object in view". They also point out that " It happens sometimes that the number of particles in a traverse is less than 50 particles. . ."

Holdsworth, Henley Price, and Tomlinson (1954), when describing the usual procedure adopted in the National Coal Board, say, in regard to traverses 30 microns wide, " The density of the deposits is usually such that 100 to 150 particles are counted at each traverse for it is considered that less than 50 or more than 200 particles per traverse would introduce serious counting errors ".

At the Pneumoconiosis Research Unit, we have been in the habit of using densities such that the total count lies between 50 and 100 particles for a traverse 40 microns wide and the count 1-5 microns diameter lies between 25 and 50 particles for a traverse 40 microns wide, although occasional samples have occurred less than half and more than twice as dense as this.

In Table 3 these densities are referred to a count corresponding to a traverse 20 microns wide for comparison with the results described earlier and for reference to Figs. 3 and 4.

The results suggest that the sample densities normally used by this Unit are such that the true airborne dust concentrations are between 5 and 15% higher than those estimated from the counts. Green and Watson (1935) recommended higher sample densities than we use but it is possible that they had in mind much finer dusts than are normally found in coal-mines and the amount of overlapping would then be much less. The Transvaal Chamber of Mines (1947) recommended densities several times greater than we normally use although here again these densities may be tolerable if the dust is very fine. The sample densities used by the National Coal Board (Holdsworth *et al.*, 1954) are between four and five times as great as those used by us, but they may make some attempt to count overlapping particles separately. However, Hicks (1952), when quoting the instructions given in a counting trial to

TABLE 3

RANGE OF DENSITY OF DEPOSIT USED BY DIFFERENT WORKERS STANDARDIZED FOR A TRAVERSE 20 MICRONS WIDE

Size Range	Worker	Count per Traverse	
		Usual Level	Range
All sizes ..	P.R.U.	25–50	12–100
	Green and Watson	56	11–1,118
	S. Africa	233	116–698
1–5 μ ..	P.R.U.	12–25	6–50
	Holdsworth *et al.*	67–100	33–133

compare the counts produced by the different Divisions of the National Coal Board, said:

> "The object of counting is to determine the number of airborne dust particles of a specified size in unit volume of air. These may be either behaving as single units or aggregates, that is, groups of adhering particles behaving as single entities. The criteria by which individuality for inclusion in the count should be judged are as follows: (i) that it falls within the specified size range; (ii) that at some stage of the focusing a clear margin of separation is visible between the particle and all its neighbours."

If this last rule is applied strictly, it seems unlikely that the counting is very different from that used in the experiment reported in this paper.

A number of workers have estimated theoretically the error due to overlapping which would be expected when particles are deposited at random on a sampling plate (see for example Armitage, 1949; Mack, 1954; 1956). However, they all make certain simplifying assumptions about the kind and size of aggregates produced which result in an underestimate of the error and are likely to be valid only when the number of particles overlapping is small. Moreover, the problem is complicated in the thermal precipitator for a number of reasons. Particles drawn into the thermal precipitator head are subjected to three main forces (Fig. 5); the force, *F*, due to the temperature gradient, the downward force of gravity *G*, and the viscous drag of the air, *R*. Consequently the particles, particularly the coarse ones, approach the depositing surface obliquely.

For a given number of particles deposited in unit area the risk of one of them being struck by an approaching particle is greater if the particle approaches obliquely than if it approaches vertically. All theoretical treatments of the problem have so far assumed that particles approach the surface vertically. This will lead to an underestimate of the actual amount of overlapping.

Another complication is that the theory assumes that the particles are equally likely to deposit anywhere on the depositing surface. In a thermal precipitator sample the density of the deposit varies over its width, being most dense near the centre; in addition coarse particles tend to deposit on one side and fine particles on the other. Also the place where a particle deposits may be influenced by particles already deposited exerting localized thermal or electrostatic effects.

Armitage (1949) derived an approximate expression for the effect of overlapping on the total number count, suitable for use when the amount of overlapping is small. He assumed the particles were laminae and were deposited at random on a sampling plate. The error in the total count predicted from these assumptions is shown by the bottom curve in Fig. 4. This error is slightly less than that found experimentally with the thermal precipitator. This could be checked by comparing the thermal precipitator with a sedimentation cell. In the sedimentation cell there is no reason to doubt that the amount of overlapping would be the same as the amount predicted by Armitage.

Conclusions

When aggregates of particles were counted as single particles the error in the number count due to overlapping which occurred at particle densities commonly used was at least 10% when sampling

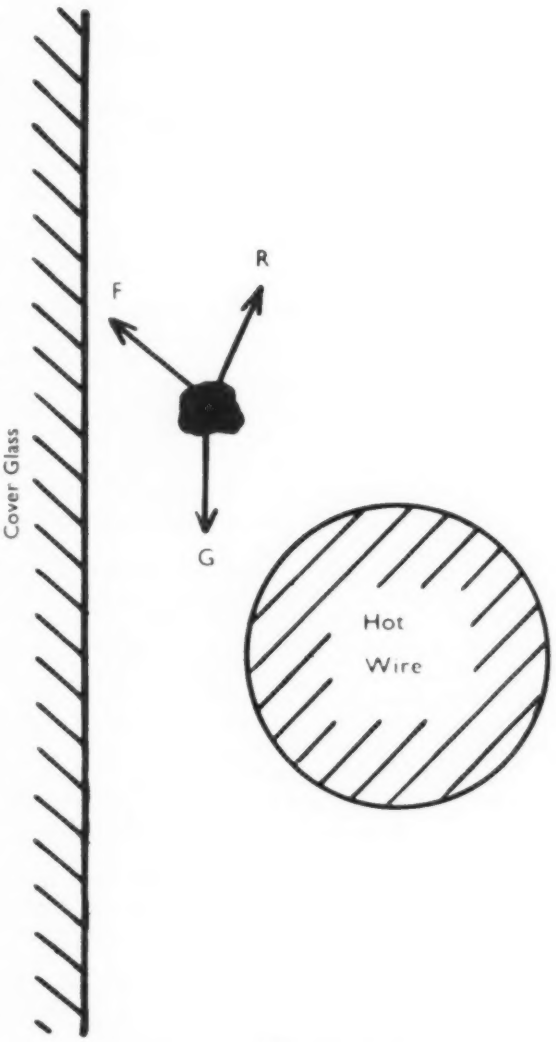

FIG. 5.—The forces on a particle in a thermal precipitator.

the airborne dust in a coal-mine. This overlap error could be reduced by using lower densities, but against this must be weighed the error due to extraneous contamination, which would then become increasingly important. Assuming a maximum contamination of 3 particles per 20 micron traverse, then the particle density required to reduce this to say 5% of the count is 60 particles per traverse, a point where the error due to overlapping is already 20%. Consequently, it does not seem to be possible in practice to avoid the difficulties introduced by overlapping particles when sampling airborne dust similar to that occurring in the mine where this investigation was made.

The overlap error would be expected to be less when sampling finer clouds. Also modifications of the standard instrument which have the effect of excluding large particles from the sample or spread the sample over a larger area are likely to be beneficial in this respect.

The effect of ignoring the overlap error is to compress the scale of dust concentration so that the average concentration is underestimated. Moreover, any changes in dustiness brought about by dust suppression are also underestimated.

In experiments to study the errors in thermal precipitator sampling it is customary to determine the repeatability of the results obtained by different instruments when sampling identically. Errors due to overlapping are not revealed in such experiments. Our results suggest that overlapping may be a serious source of error which should not be ignored.

Errors due to overlapping may produce misleading results when comparing different types of instruments. For example, Burdekin and Dawes (1956) compared the results of counts obtained using a standard thermal precipitator with those obtained using a thermal precipitator with an elutriator attachment to trap the larger particles before entering the instrument. Such a comparison would have only a limited value if high sample densities were used, as the effect of overlapping would be much less on the samples with a few large particles. Hamilton (1956) compared the results of counts obtained using a standard thermal precipitator with those obtained using a long-running thermal precipitator. The effect of overlapping on the counts obtained is likely to be different in the two instruments, as the long-running thermal precipitator has an elutriator attachment to trap large particles and in addition the depositing surface has a relatively large area.

Summary

In a thermal precipitator sample some particles overlap others and in consequence the concentration may be underestimated. The magnitude of this error has been estimated from a comparison of counts of pairs of samples taken in a colliery in which one sample of each pair was five times as dense as the other. This method of testing the instrument does not appear to have been reported previously.

It was concluded that the error in the number count due to overlapping which occurs at particle densities commonly used and recommended is large and cannot be ignored. This conclusion was supported by comparison with the error expected from theoretical considerations.

With the standard thermal precipitator the particle density required to reduce the overlap error to negligible proportions appears to be so low that its value as a standard reference instrument in coal-mines is open to doubt and needs reinvestigation against an absolute standard.

Mr. P. D. Oldham of the Pneumoconiosis Research Unit suggested this experiment. The work was carried out by Messrs. B. P. Pryce, R. P. Pryce, and W. J. Davies, and the results were analysed by Dr. M. E. Wise. I would also like to thank Dr. J. C. Gilson, the Director of this Unit, for his many valuable suggestions in the preparation of this paper.

REFERENCES

Armitage, P. (1949). *Biometrika*, **36**, 257.
Burdekin, J. T., and Dawes, J. G. (1956). *Brit. J. industr. Med.*, **13**, 196.
Green, H. L., and Watson, H. H. (1935). *Spec. Rep. Ser. med. Res. Coun. (Lond.)*, No. 199.
Hamilton, R. J. (1956). *J. sci. Instrum.*, **33**, 395.
Hicks, D. (1952). *The Sampling and Analysis of Airborne Dust for Control Purposes*. Meeting of Experts on the Prevention and Suppression of Dust in Mining, Tunnelling and Quarrying. International Labour Office, Geneva.
Holdsworth, J. F., Henley Price, F., and Tomlinson, R. C. (1954). *Brit. J. appl. Phys.*, Suppl. 3, *The Physics of Particle Size Analysis*, p. 96.
Irwin, J. O., Armitage, P., and Davies, C. N. (1949). *Nature (Lond.)*, **163**, 809.
Mack, C. (1954). *Proc. Camb. Phil. Soc.*, **50**, 581.
—— (1956). *Ibid.*, **52**, 246.
Transvaal Chamber of Mines (1947). *Quality of Mine Air*. Johannesburg.

Brit. J. industr. Med., 1958, **15**, 258.

RESPIRATORY FUNCTION OF WITWATERSRAND GOLD-MINERS

A COMPARISON BETWEEN RADIOLOGICALLY NORMAL MINERS AND CONTROL NON-MINING SUBJECTS

BY

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The diagnosis of pneumoconiosis during life depends upon an industrial history and radiological examination (Carpenter, Cochrane, Gilson, and Higgins, 1956). However, many miners complain of dyspnoea but have no radiological changes at all. This has led to the supposition that long exposure to industrial dust hazards may lead to pulmonary disability which is not typical pneumoconiosis (Carpenter, and others, 1956; Pemberton, 1956). This disability might be due to a *forme fruste* of pneumoconiosis or something different, such as chronic bronchitis and emphysema (Pemberton, 1956). It is obviously important in the first place to establish whether, in the mining population as a whole, there is any impairment of pulmonary function which is unassociated with radiological disease. A method of investigating this hypothesis is to compare the pulmonary function of a random selection of radiologically normal miners with a control group of equivalent age, physique, and socio-economic status. This paper describes such a study.

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Material and Methods

An annual examination at the Pneumoconiosis Bureau, Johannesburg (including clinical and radiological examination) is compulsory for all working miners, for all retired miners who wish to retain the right to mine, and for those who have left the industry and are in receipt of compensation until such time as their compensation reaches the maximum level. Thus, examination of the Bureau records makes it possible to compile a fairly complete list of miners (present and past) in any one radiological category. The names of 30 gold-miners or ex-miners were selected at random from the records of all men examined at the Bureau during the period December, 1955, to May, 1956, and these men were recalled for testing.

The only criteria for selection were a history of at least seven years' underground service (Table 1) and a chest radiograph within normal limits. The radiographs were read independently by at least two observers. As all miners are radiographed routinely every six months, comparison with previous radiographs and their readings was subsequently made in every case in order to detect the earliest signs of silicosis. No doubtful cases were included. Ten men in each age group, 31 to 40, 41 to 50, and 51 to 60 years, were thus chosen.

The control group consisted of 30 working artisans

TABLE I

PHYSICAL CHARACTERISTICS OF SUBJECTS STUDIED AND INCIDENCE OF CHRONIC BRONCHITIS, EMPHYSEMA, AND BRONCHIAL SPASM (PEMBERTON, 1956)

Group	No. of Subjects	Mining Service		Age		Height		Weight		Surface Area		Pemberton's Groups			
		Years	S.D.	Years	S.D.	cm.	S.D.	kg.	S.D.	sq. m.	S.D.	I	II	III	IV
31–40 *Years*															
Railway workers	10			35·30	2·83	173·10	6·39	77·10	11·46	1·9080	0·1480	9	1	—	—
Miners	10	14·98	3·55	37·90	2·47	177·00	5·16	83·20	10·20	2·0020	0·1360	8	1	—	1
41–50 *Years*															
Railway workers	10			45·40	2·63	178·40	6·10	71·60	8·89	1·8840	0·1380	6	3	1	—
Miners	10	17·00	3·07	45·00	2·21	175·60	5·80	78·50	11·40	1·9360	0·1637	7	2	1	—
51–60 *Years*															
Railway workers	10			55·20	2·70	171·80	4·54	71·80	8·08	1·8420	0·1250	7	1	1	1
Miners	10	21·50	6·08	54·80	3·16	169·00	4·59	74·40	7·62	1·8480	0·1056	9	1	—	—

from a railway workshop (population 700 men). They were asked to volunteer and then put into one of the three age groups to match the miners. The only criteria for rejection were a full age group, a history of exposure to silica dust, or any radiological abnormality of the chest. It was our impression that they were comparable as regards their socio-economic status and their physical activity at their respective occupations. The mean age, height, weight, and body surface area of each group is recorded in Table 1.

In all subjects a careful industrial and clinical history was obtained with particular emphasis on respiratory symptoms. Dyspnoea was graded on the scale suggested by Fletcher (1952). A clinical examination was made and radiological, electrocardiographic, and haematological examinations were carried out in each case. Lung function testing was performed using the methods previously described by Becklake, du Preez, and Lutz (1958), whose paper contains the results on the same 20 miners aged 41 to 60 years as are herein reported. Values are tabulated for comparison in Tables 2 and 3.

All lung volumes and ventilatory capacity values are corrected to B.T.P.S. The difference between the mean value for any one test in the miners and that for the control group was tested for significance using Student's t test.

Results

Tables 2 and 3 report the mean and standard deviation of each test in each group of 10 men. Values for residual volume and functional residual capacity are similar. Vital capacity is slightly greater in miners in two age groups. The miners in these groups have consequently a slightly greater total lung capacity of which a slightly smaller percentage is taken up by the R.V. or F.R.C. respectively.

Tests of mixing efficiency and arterial oxygen saturation (oximetry) reveal no significant differences. The values for ventilation equivalent on effort suggest that there was a tendency for miners to have a greater ventilatory response to exercise, but this was significant at the 5% level in the 41 to 50-year-old age group only, and no significant differences were noted in the Hugh-Jones test. However, it is possibly related to the fact that the miners spend a number of hours each working day at a considerable depth below the surface where the oxygen tension is higher (altitude of Johannesburg 5,760 feet above sea level). The miners might, therefore, be less well adapted to altitude (Stickney and Van Liere, 1953) than the railway workers, but no detailed investigation on this problem has yet been attempted here.

Though the mean values for maximum voluntary ventilation suggest that the rate of fall with age is higher in the miners than the railway workers, there is no significant difference in the two regressions of M.V.V. on age, owing to the wide variation of individual values. Maximum mid-expiratory flow rates, while almost identical in the two younger age groups, are significantly different in the oldest group at the 5% level. Possible technical errors were eliminated when the railway workers aged 51 to 60 years were re-tested, and the same low result for the maximum mid-expiratory flow rate was obtained. The interpretation of this observation is, however, uncertain when it is seen that in the same age group there is a tendency for the miners to have a lower maximum voluntary ventilation, lower compliance, higher non-elastic expiratory resistance, and a lower maximal expiratory pressure. In the age group 31 to 40 years also, the miners have a significantly higher expiratory resistance, but not in the 41 to 50 group.

It thus appears that in a few tests only was there a significant difference between the mining and control groups and where such differences were present they were not consistent in all age groups. In a previous study, using identical testing techniques (Becklake, and others, 1958), it has been shown that by the technique of discriminant analysis a cumulative test score could be derived by which it was possible to separate miners with radiological changes of silicosis from those without, in spite of the fact that no individual test was capable of producing such separation. However, the application of this technique to the present data completely failed to show any significant difference between the miners and the control group. Also, when the results for V.C., R.V., T.L.C., F.R.C., and M.V.V. were expressed as a percentage of the predicted values* no significant differences were detected.

Finally, using Pemberton's (1956) criteria † both miners and railway workers were placed in one of his four diagnostic groups for chronic bronchitis, emphysema, and bronchial spasm (Table 1). No significant difference in the incidence of these illnesses in miners and non-miners was found.

Discussion

There are few published reports of a comparison between radiologically normal miners and control groups composed of men who have never been exposed to the dust hazard. Craw (1947), in a comparison of non-miners and haematite miners, found no significant differences in the results for an exercise test and lung volumes between miners with normal radiographs, those with "reticulation", and the controls. Vokac (1950) found a reduction of M.B.C. but not of V.C. in non-silicotic miners when com-

*Based on a study of 44 normal males and 50 normal females resident on the Witwatersrand at an altitude of ± 6,000 feet. (Goldman and Becklake, to be published.)

†Substituting the M.M.F. for the timed vital capacity used by Pemberton.

pared with a control group of normal non-miners. Gilson, Hugh-Jones, Oldham, and Meade (1955) compared coal-miners selected purely on the basis of age and radiographic appearance with men applying for work at an employment agency. The latter were asked to volunteer for lung function tests, and were excluded only if they had had mining experience, or were physically handicapped, or had detectable abnormality on examination by the usual clinical methods. Their study included the application of a wide range of lung function tests. The only test in which important differences were noted between non-miners and miners was the maximum voluntary ventilation, and this was reflected in higher values for the dyspnoeic index in the mining group than in the non-mining control group.

TABLE 2
RESULTS OF LUNG VOLUME STUDIES, MIXING, AND EXERCISE VENTILATION

Group	Vital Capacity (V.C.) in Litres	Residual Volume (R.V.) in Litres	Total Lung Capacity (T.L.C.) in Litres	Functional Residual Capacity (F.R.C.) in Litres	R.V./T.L.C. (%)	F.R.C./T.L.C. (%)	Mixing Index of Becklake and Goldman (1954) in l./litre F.R.C.	Oximetry† % Change on Effort	Ventilation Equivalent‡ for Oxygen on Effort (l./100 ml. O_2 uptake)	Effort Test at a Work Load of 350 kg.-m./min. (Hugh-Jones and Lambert, 1952)			
										Resting Ventilation (l.)	Exercise Ventilation (l.)	Standard Ventilation (l.)	Dyspnoeic Index (%)
31–40 *Years*													
Railway workers	4·868	1·488	6·352	3·117	23·50	49·20	3·595	5·67	2·48	11·78	31·64	32·82	20·50
S.D.	0·580	0·368	0·724	0·613	4·45	8·42	0·411	2·32	0·44	2·07	4·40	5·54	5·80
Miners	5·290	1·586	6·962	3·148	23·20	45·10	3·370	5·95	3·03	12·54	33·67	36·77	23·40
S.D.	0·994	0·238	0·944	0·640	4·32	5·36	0·827	3·70	0·73	2·52	5·93	9·87	8·26
41–50 *Years*													
Railway workers	4·775	1·973	6·738	3·666	29·40	54·10	3·158	6·08	2·35*	11·30	30·30	34·15	21·10
S.D.	0·634	0·381	0·682	0·735	5·39	9·07	0·722	1·76	0·58	3·08	4·96	7·25	5·34
Miners	4·831	1·928	6·812	3·513	28·20	51·60	3·330	5·23	2·99	—	—	—	—
S.D.	0·753	0·507	0·980	0·737	5·75	8·97	0·558	2·74	0·56	—	—	—	—
51–60 *Years*													
Railway workers	4·373	2·157	6·540	3·634	33·10	55·70	3·526	5·86	2·81	11·24	38·80	41·33	28·30
S.D.	0·436	0·309	0·606	0·600	3·18	5·70	0·439	1·17	0·56	2·03	5·89	7·27	8·17
Miners	4·302	2·046	6·395	3·242	32·10	49·70	3·848	6·13	3·16	11·93	33·90	35·30	30·90
S.D.	0·633	0·368	0·912	0·709	4·23	7·32	0·548	2·35	0·58	2·15	3·32	3·67	7·26

*Differs from the value for mineworkers at the 5% level using Student's t test.

†The sum of the maximal fall in arterial oxygen saturation on standard effort plus the maximal rise in arterial saturation on breathing pure oxygen. This figure is based on the assumption that all subjects became 100% saturated on breathing pure oxygen. Thus the sum of the recorded deviations from the resting value, resulting first from effort and then from oxygen breathing at rest, represents the total percentage fall from 100 produced by effort.

‡Ventilation equivalent at an exercise requiring one litre oxygen uptake per minute (in litres ventilated per 100 ml. oxygen uptake).

TABLE 3
RESULTS OF WORK OF BREATHING STUDIES

Group	Maximum* Voluntary Ventilation ($M.V.V._{F.}$) in l./min.	Maximal Mid-expiratory Flow (M.M.F.) in l./sec. (Leuallen and Fowler, 1955)	At Rest			Fall in Compliance on Hyper-ventilation at f ± 50/min.	Mean Resting End Expiratory Pressure ($cm.H_2O$)	Maximum Expiratory Pressure (mm.Hg)
			Compliance in $l./cm.H_2O$ (Mead and Whittenberger, 1953)	Expiratory Non-elastic Resistance in $cm.H_2O/l./sec.$ (Mead and Whittenberger, 1953)	Breathing Frequency/min. (f.)			
31–40 *Years*								
Railway workers	169·9	3·58	0·183	2·60†	18·4	—0·022	—3·650	99·0†
S.D.	26·8	0·86	0·031	0·21	6·9	0·020	2·195	15·1
Miners	167·3	3·87	0·228	3·10	18·1	—0·018	—3·299	127·0
S.D.	38·8	1·41	0·054	0·98	5·2	0·037	1·179	37·3
41–50 *Years*								
Railway workers	166·4	3·13	0·190	3·23	15·3	—0·022	—4·460	82·0
S.D.	27·8	1·55	0·050	0·80	3·5	0·024	1·794	22·7
Miners	147·4	3·12	0·234	3·02	19·9	—0·015	—3·550	—
S.D.	33·5	1·06	0·052	0·89	4·7	0·044	0·989	—
51–60 *Years*								
Railway workers	134·2	1·68†	0·206	3·06†	18·8	—0·083	—2·560	90·0
S.D.	36·3	0·41	0·038	0·37	3·9	0·094	1·034	27·0
Miners	119·9	2·38	0·199	4·39	16·9	—0·042	—4·580	76·0
S.D.	29·8	0·91	0·044	1·06	2·3	0·057	1·696	18·9

*Terminology recommended by Gandevia and Hugh-Jones (1957).

†Differs from the value for mineworkers at the 5% level using Student's t test.

Pemberton (1956), in a largely clinical study, compared a group of coal-miners with two groups of industrial workers. He found chronic bronchitis, emphysema, and bronchial spasm commoner in miners than in the industrial workers, and amongst the former its incidence was unrelated to the presence of pneumoconiosis. Expressed differently, miners with a normal chest radiograph were found to have a higher incidence of these respiratory illnesses than non-miners and evidence was presented suggesting that this was occupational in origin. Our results are not in agreement but it is not unreasonable to expect that a certain concentration of coal dust inhaled by his subjects might produce different results from the relatively low concentration of silica dust inhaled by the Witwatersrand gold-miner.

From Table I the interesting fact emerges that there is only six and a half years' difference in the length of underground service between the miners aged 31 to 40 and those aged 51 to 60 years. This suggests the possibility that the disabled miners with longer underground service may have left the industry, but, as pointed out earlier in this paper, such men would still present themselves for examination at the Pneumoconiosis Bureau and would be included in our sample. It is, perhaps, more likely that men with longer service would show some radiographic changes which would have automatically excluded them from this survey.

Although in two age groups the non-elastic expiratory resistance is significantly higher in the miners, if all the tests are considered together it appears that no obvious difference had been disclosed between miners and controls in this study. However, it cannot be concluded that mining causes no disability other than that associated with radiologically evident silicosis. The test battery employed here, though fairly comprehensive, cannot be said to have tested all aspects of lung function nor was the series examined large enough to exclude the possibility that mining causes disability in a small percentage of more susceptible individuals.

Short of an effective random sample of the whole population of a geographically defined area, unfortunately seldom practicable, the procedure was chosen of testing as controls a population of similar age, physique, and socio-economic status engaged in an occupation involving a similar degree of physical activity but known not to have been exposed to silica dust. However, as soon as the control group is selected by calling for volunteers it ceases to be fully representative (Pemberton, 1956; Schilling, 1957), nor can it be certain that the railway workers themselves do not suffer from a higher incidence of respiratory disease than the general population due to the nature of their employment. This difficulty is partially answered by the fact that the mean values for vital capacity, residual volume, total lung capacity, functional residual capacity, and maximum voluntary ventilation in both miners and railwaymen fall within the predicted normal limits using the prediction formulae of Goldman and Becklake (to be published).

It is concluded that comparison of radiologically normal miners and railway workers by the methods used in this study has failed to demonstrate conclusive clinical or physiological evidence of an increased incidence of chest disability in the former.

Summary

Lung function studies were made in a random sample of the Witwatersrand gold-miners and exminers with normal chest radiographs in the ages 31 to 60 and compared with an age-matched group of volunteers from railway workshops. Ten subjects in each 10-year age group were studied. The incidence of chronic bronchitis, emphysema, and bronchial spasm was assessed using criteria suggested by Pemberton.

No conclusive evidence, clinical or physiological, of an increased respiratory disability among the mining group was obtained, although the average maximum breathing capacity was lower in the miners over the age of 40, but the differences were not statistically significant.

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References

Becklake, M. R., and Goldman, H. I. (1954). *S. Afr. J. med. Sci.*, **19**, 21.
——, du Preez, L., and Lutz, W. (1958). *Amer. Rev. Tuberc.*, **77**, 400.
Carpenter, R. G., Cochrane, A. L., Gilson, J. C., and Higgins, I.T.T. (1956). *Brit. J. industr. Med.*, **13**, 166.
Craw, J. (1947). *Silicosis, Pneumokoniosis and Dust Suppression in Mines* p. 68. (Proceedings of a Conference.) Published jointly by The Institution of Mining Engineers and The Institution of Mining and Metallurgy, London. Quoted by Gilson and others (1955).
Fletcher, C. M. (1952). *Proc. roy. Soc. Med.*, **45**, 577.
Gandevia, B., and Hugh-Jones, P. (1957). *Thorax*, **12**, 290.
Gilson, J. C., Hugh-Jones, P., Oldham, P. D., and Meade, F. (1955). *Spec. Rep. Ser. med. Res. Coun. (Lond.)*, No. 290.
Goldman, H. I., and Becklake, M. R. To be published.
Hugh-Jones, P., and Lambert, A. V. (1952). *Brit. med. J.*, **1**, 65.
Leuallen, E. C., and Fowler, W. S. (1955). *Amer. Rev. Tuberc.*, **72**, 783.
Mead, J., and Whittenberger, J. L. (1953). *J. appl. Physiol.*, **5**, 779.
Pemberton, J. (1956). *Arch. industr. Hlth*, **13**, 529.
Schilling, R. S. F. (1957). *Brit. J. industr. Med.*, **14**, 145.
Stickney, J. C., and Van Liere, E. J. (1953). *Physiol. Rev.*, **33**, 13.
Vokac, Z. (1950). *Pracov. Lék.*, **6**, 336. Quoted by Gilson and others (1955).

Brit. J. industr. Med., 1958, **15**, 262.

A STATISTICAL STUDY OF COAL-MINING ACCIDENTS

BY

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Statistics of accidents in British coal-mines have been collected in one form or another since 1873 (Ministry of Power, 1957). From those early days there has been a steady decline in the numbers of fatalities but even now more than 300 men a year are killed in mining accidents. About a million and a half injuries, varying from the trivial to the fatal, are reported in a year and coal-miners, who form only about a twentieth of the insured male population of Great Britain, account for nearly half of all industrial injuries attracting benefit.

Because of, on the one hand, the requirements of the Mines Inspectorate of the Ministry of Power, and, on the other, arrangements for compensation, casualties* in the industry are classified into the following four categories:

(*a*) Fatal casualty.

(*b*) Other "reportable" casualty: a report must be made to the Mines Inspectorate of any case of "serious personal injury" (such as a major fracture) and of every "dangerous occurrence".†

(*c*) Other compensable casualty: an injury which causes absence from work for more than three days and which is therefore compensable under the National Insurance (Industrial Injuries) Act.

(*d*) Non-compensable casualty, *i.e.*, any casualty not included in the three categories above.

Although the great majority of casualties are in category (*d*), the compensable casualties, *i.e.*, those in categories (*a*) and (*c*) together with most of those in (*b*), amount at present to over 200,000 a year. For the years 1945 to 1949 inclusive, certain information about these casualties was reported to the Ministry of Power where a card was punched for each casualty. It was natural to assume that this material, consisting of over 900,000 cards, would be a reasonable source of data for statistical research. The material (data A) was, therefore, borrowed by the National Coal Board and the work described below was carried out on it. Work was also done by the technical section of the Board's central Statistics Branch on more detailed and more up-to-date material (data B) relating to 14 collieries only—less than 2% of those in the Board. The third source of material (data C) was available in the shape of colliery accident rates and other colliery statistics. These data are described in detail below.

Despite the vast amount of data available, the conclusions were mainly negative. This was largely because standards of recording and habits of reporting appeared to differ appreciably and because the background information necessary for detailed work was not available. There were, however, a number of positive findings which are discussed in this paper.

The Data

The three bodies of data studied are described below:

Data A.—For each compensable casualty occurring in the five years 1945 to 1949, one 45-column Powers-Samas card had been punched. The data, obtained from a statutory return, contained information about the man involved, the time, place, and cause of accident, the resulting injury, and the length of absence which followed.

Data B.—For each compensable casualty occurring during 1953 at eight collieries in one area, *X*, and at six collieries in another area, *Y*, in a different division* one 80-column Hollerith card had been punched. The data were obtained from an accident

*In this paper "casualty" refers to a man injured in an "accident". An accident may cause more than one casualty, and a casualty may have more than one injury.

†See Ministry of Power (1957) for a definition of "reportable" accidents. (New regulations have since changed this definition.)

*There are 900 collieries in the N.C.B. grouped into 51 areas which are further grouped into nine divisions.

report form which had been coded at divisional level. The information punched was similar to that of data A, but more detailed.

Data C.—One punched card for each colliery contained two accident rates for both 1953 and 1954: underground (number of compensable underground casualties per 100,000 manshifts worked underground) and surface (number of compensable surface casualties per 100,000 manshifts worked on the surface). A variety of descriptive information about the colliery is also available on the card, which forms part of the " colliery profile ".*

Classification of Casualties.—All the data described above relate to compensable casualties, including, at the extremes, fatalities, and men suffering from minor injuries, but excluding injuries not causing at least four days' absence. The distinction between the categories of casualty described above is, of course, largely arbitrary and it is instructive to compare the rates of compensable casualties with those for other categories.

If habits of reporting and standards of recording did not vary, it would be expected that a group of collieries which are " safe " would have a low rate for each category of injury, whereas collieries which are " dangerous " would have high rates.

Fatal accidents are too rare to allow of an examination for individual pits over any reasonable period of time, but it is possible to study figures for N.C.B. divisions. On the hypothesis that the rates of the various categories of casualty each reflect the degree of safety in a division, we would expect a high correlation between each pair of rates. In fact, such correlations are not found except between the rates of fatalities and of other reportable casualties, and here the correlation coefficient is $+0{\cdot}8$. In no other case is there any trace of the positive association that our hypothesis would lead us to expect.

Confirmation can be found in an examination of area rates. There is no correlation between the rates of fatal and non-fatal (compensable) accidents in 1954, but since there are few fatal accidents in any area in one year the rates are rather unreliable. However, there is no trace of correlation between area rates of all reportable casualties (categories (*a*) and (*b*) combined) and rates of other compensable injuries.

Further evidence is found in Fig. 1, where fatal, reportable, and compensable rates are compared from 1927 to 1957. Obviously there is less possibility of anomalies in recording fatal and reportable injuries than with other categories, and it can be seen that these two rates, which might be expected to reflect the true danger of coal-mining as an occupation, have been decreasing steadily, while the compensable accident rate rose steeply in 1948, the year in which the National Insurance (Industrial Injuries) Act came into force.

Since the two rates found to be associated are those which are least open to question it would appear that the hypothesis being examined is untenable. In other words the compensable accident rate does not appear to be a true reflection of the degree of safety, but depends on such factors as habits of reporting.

Differences in Recording of Data.—That there are differences in recording is not surprising. There is one form of report available throughout the industry for accidents which are not statutorily reportable to H.M. inspectors of mines, but it is not used in every colliery and where it is used it is completed under diverse local instructions by men with varying responsibility.

It should be borne in mind that none of the information had been collected for research purposes, and discrepancies and shortcomings, which suggested that too detailed an examination could not be justified, were inevitable. For example, the percentage of answers in the category " cause of accident " that were coded as " unclassified " in data B was in some collieries over 90% and for surface workers was never lower than 40%. There were important differences between collieries in their use of the coding " unclassified " which were clearly due to different habits of recording. Furthermore, discrepancies such as the recording of the place of an accident as " elsewhere underground " when its recorded cause is one specific to the coalface, were found frequently enough to reflect on the value of the material. In addition, large and consistent differences were found in data B between the two areas: the pits in Area *X* had higher accident rates than those in Area *Y*, but their absences were considerably shorter.

It was found in data A that collieries used two different methods of recording the length of absence; some collieries recorded absences consisting of a number of weeks plus anything up to six days but the majority recorded absences of a number of weeks and only up to five days. It appeared, too, that the day of start of absence and day of return to work might or might not be included in the absence; in some collieries only complete weeks of absence were recorded. Similarly, in data B absences of six, 13, 20, etc., days were never obtained. There seemed to be a definite tendency for men to be recorded as returning to work after having had

*See Liddell (1955) for a description of the " colliery profile " for 1953.

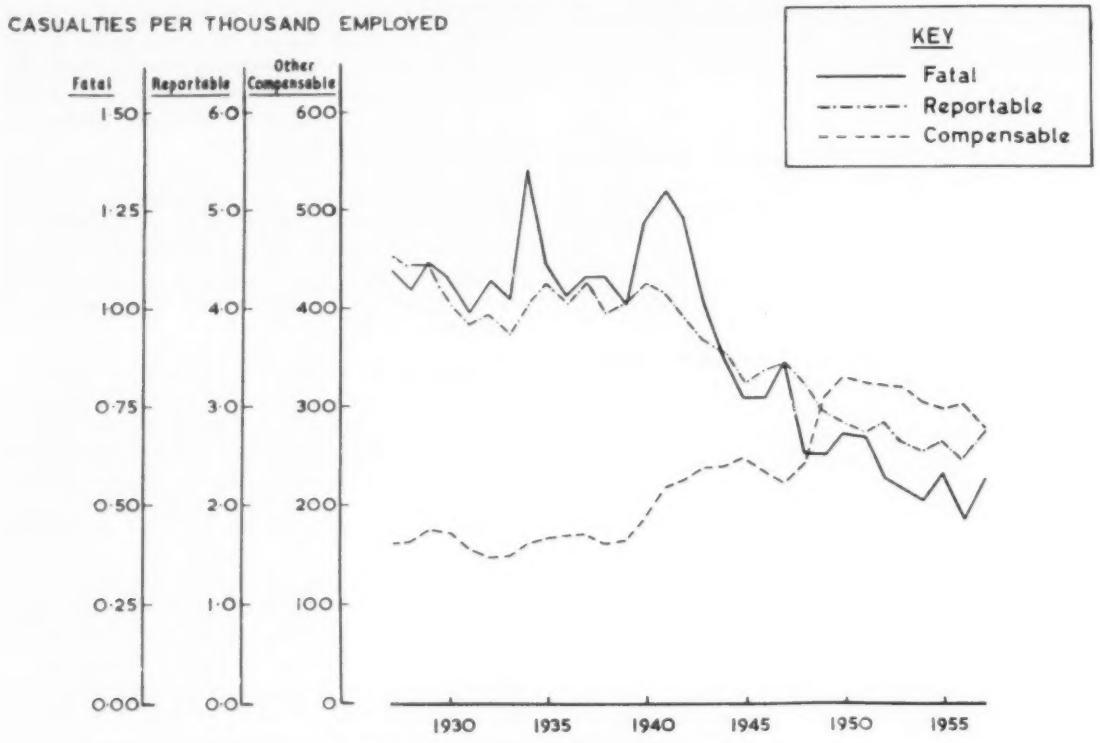

FIG. 1.—Accident rates in British coal-mines, 1927-57.

absences of complete weeks irrespective of the day of the week on which the accident had occurred. For these reasons the data contained extremely irregular distributions of absence.

It was possible to obtain some details of manpower and manshifts to give denominators and enable us to compute accident rates for certain groups, for both data A and data B, but there were difficulties here also. In particular the breakdown of the population by age and occupation simultaneously was not available.

Finally, it must be remembered that not only do mining methods and environmental conditions vary widely from colliery to colliery (and indeed in many cases within the colliery from coalface to coalface) but also that similar occupations are defined differently in different pits. Hence strictly comparable conditions are hard to find and casualty rates for a colliery reflect a whole complex of situations.

Analysis of Data

Despite these drawbacks, it was felt that, as this material was the first of its kind available in the coal industry, it was worth detailed examination. A number of results which appear reliable and instructive were obtained and are discussed below.

Methods.—Wherever possible, both incidence and length of absence following an accident were examined, using the following measures:

(a) " *Casualty rate* ", taken as the number of casualties occurring in a particular class of worker divided by the number of men in this class. (The casualties refer to a year's experience but the numbers of men are those employed in a particular week in the year. Thus the numerator and denominator of the rate are not strictly comparable.)

(b) " *Accident rate* ", taken as the number of casualties divided by the number of manshifts worked over the year.

(c) " *Length of absence* ", taken as the median length. All those absences which were " not recovered "* were counted as greater than the median.

The use of the median length of absence requires justification. This measure is not unreliable when based on large numbers of casualties: its particular virtue is that it takes reasonable account of the " not recovered " cases, and is not unduly affected by occasional very long absences. However, as already explained, the distribu-

*Under " period of disablement " collieries were instructed to enter " not recovered " if the person had not returned to work when the statutory return was sent to H.M. Inspector of Mines, which would have been by January 21 of the following year.

tions of length of absence are very irregular, and so the median should be regarded with caution.

Because of the nature of the distribution of lengths of absence, the median is always considerably lower than the arithmetical average. A study carried out on the figures for 1951 which traced back the length of absences in the vast majority of cases (thus reducing the " not recovered " class to a minimum) gave a mean length of absence of 27 working days. This compares with a median figure of some 18 days estimated in our present study for 1949, using data A.

Since data A refer to nearly a million casualties in all, it was always necessary to work with samples of collieries. A separate sample was taken for each study; a description of each sample is given in the appropriate section.

Throughout these studies it was found that accident experience differed significantly between the three main places of work: coalface, elsewhere underground, and surface. Coalface workers had the highest rate, then workers elsewhere underground; surface workers had the lowest rate. This pattern was consistent from pit to pit and from year to year. It was clear that the three places had to be kept separate in all further studies.

Results

Accident Experience and Age.—Data A and B were used to study this factor. From data A, samples of 10 collieries were taken for each of the years 1948 and 1949, these years being both convenient and the latest for which data were available. No colliery was included in both samples. No collieries employing fewer than 1,000 men were included, because the numbers of men and of casualties in the subclasses examined would be too small to provide a reasonable basis for analysis. Further, the manpower returns for 1949 referring to one division were not available, and that division was therefore excluded from the sample for that year.

The results from the two sources are remarkably similar, despite the differences in coverage.

In Table 1, the casualty rates, based on numbers of men employed in age groups, are given for data A. There is a considerable increase in the rates over the two years covered. The provisions of the National Insurance (Industrial Injuries) Act and of the Supplementary Scheme for Colliery Workers came into force in July, 1948, and may have had something to do with this effect.

The results for data B were similar and such differences as there were are probably accounted for by the differences in geographical coverage of the two bodies of data, even although data B were for 1953.

There was an overall tendency for the casualty rate to decrease with age. This might be due to such factors as greater carelessness in younger men, or to a tendency for younger men to report injuries more freely, or for them to be given the most dangerous work. Within each age group it was clear that coalface workers had the highest casualty rates and surface workers the lowest.

TABLE 1

CASUALTY RATES BY AGE AND PLACE OF WORK: DATA A
(Number of casualties per man employed)

Age	Year	Place of Work		
		Coalface	Elsewhere Underground	Surface
Under 21	1948	0·73	0·28	0·17
	1949	0·74	0·46	0·25
21 to 30	1948	0·35	0·24	0·10
	1949	0·53	0·37	0·21
31 to 50	1948	0·39	0·20	0·09
	1949	0·57	0·26	0·15
51 and over	1948	0·46	0·17	0·08
	1949	0·47	0·18	0·10
Total ..	1948	0·39	0·21	0·10
	1949	0·55	0·28	0·16

There was an overall tendency for the length of absence to increase with age, except for men under 21. Within each age group there was the same pattern of length of absence as for all men, namely, coalface workers had the shortest absences of their age group. The figures for data B are shown in Table 2. Those for data A are again in close agreement, although they are less reliable on account of a large proportion of " not recovered " casualties.

TABLE 2

LENGTH OF ABSENCE BY AGE AND PLACE OF WORK: DATA B
(Median length of absence in days)

Age	Place of Work		
	Coalface	Elsewhere Underground	Surface
Under 21	15	18	17
21 to 25	15	17	15
26 to 30	15	18	18
31 to 40	16	19	18
41 to 50	19	24	21
51 to 55	22	23	23
56 and over	24	26	28
Total	17	21	19

The fact that the older men experienced longer absences wherever they were working might have been because they tended to incur a disproportionate number of serious injuries. In order to examine this possibility it was necessary to group the casualties by age and by severity of injury simultaneously. The groupings of injuries, which were only slightly different for the two sets of data, are given overleaf.

Using data A for 1949, Table 3 shows casualty rates by age and type of injury. It is clear that there is very little difference between the age groups in the incidence of serious injuries but that for the less severe injuries there is a steady decrease in the rates

Type	Data A	Data B
1 (Slight)	Bruises	Bruises
2	Cuts, foreign bodies, sprains	Cuts, foreign bodies, lacerations, penetrating wounds
3	Burns, rupture, strains	Burns, rupture, strains, sprains
4 (Serious)	Crushing, fractures, dislocations, concussion, amputations, asphyxiation, electric shock, carbon monoxide poisoning	Crushing, fractures, dislocations, concussion, amputations, asphyxiation, electric shock, carbon monoxide poisoning

TABLE 3

CASUALTY RATES BY AGE AND TYPE OF INJURY: DATA A (1949)

(Number of casualties per man employed)

Place of Work	Type of Injury	Age			
		Under 21	21 to 30	31 to 50	51 and over
Coalface	1 (Slight)	0·26	0·20	0·22	0·17
	2	0·30	0·19	0·18	0·16
	3	0·12	0·08	0·08	0·07
	4 (Serious)	0·03	0·02	0·03	0·03
Elsewhere underground	1 (Slight)	0·18	0·13	0·09	0·07
	2	0·12	0·11	0·09	0·05
	3	0·04	0·05	0·05	0·03
	4 (Serious)	0·03	0·02	0·02	0·02
Surface	1 (Slight)	0·08	0·07	0·04	0·03
	2	0·08	0·07	0·05	0·04
	3	0·04	0·03	0·04	0·02
	4 (Serious)	0·01	0·01	0·02	0·01

with increasing age. This pattern was not, however, consistent from pit to pit.

For data B, the pattern was not so clear cut, and a closer study was made which showed differences between the two areas. However, the rates of serious casualties were found to be comparatively consistent but the minor casualty rates were more diverse. This suggests that the differences in the patterns are due to varying willingness to report minor injuries rather than to differences in the true incidence of accidents.

Table 4 shows for data A the length of absences according to age and type of injury. Except for the youngest group, the lengths of absences increase with age; but the most noticeable result is that the under-21s take as long as the over-50s to return to work after serious injury. Again it is of interest that the length of absence does not vary markedly from one place of work to another when account is taken of both age and severity of injury. This result is confirmed from data B.

TABLE 4

LENGTH OF ABSENCE BY AGE AND TYPE OF INJURY: DATA A

(Median length of absence in days)

Place of Work	Type of Injury	Age			
		Under 21	21 to 30	31 to 50	51 and Over
Coalface	1 (Slight)	18	14	16	22
	2	17	15	17	22
	3	23	14	18	21
	4 (Serious)	74*	48	52	78
Elsewhere underground	1 (Slight)	15	14	18	24
	2	18	18	18	28
	3	23	15	23	30
	4 (Serious)	126	53	66	120
Surface	1 (Slight)	15	14	16	24
	2	16	14	22	21
	3	18	16	28	56
	4 (Serious)	77*	39	43	80

*Based on small numbers

Accident Experience and Occupation.—This section describes an examination of the casualty rates of men of different occupation within the mining industry. Although age is an important factor, as reported above, it had to be ignored here since distributions of the population by age and occupation simultaneously were not available.

For data A, a sample of 20 collieries was chosen from among the larger in the industry. It was impossible to include small collieries, for in the detailed breakdown of the figures required for this study, the number of casualties in such pits would be too small to allow of any reliable comparisons. As before, one division had to be excluded. The following occupational groups were used:

At the coalface .....Getting, ripping, "others"
Elsewhere underground.....Haulage, "others"
On the surface .....Surface work

For data B it was possible to obtain rates for three pieceworker categories only:

At the coalface .....Coal-getters (hewers, fillers, composite workers); drillers and cutter men; conveyor shifters

Casualty rates were computed from data A for each of these classes of occupation, and corresponding accident rates were obtained from data B. It was found that there was no single occupation, within the places of work, which consistently had high or low rates in most collieries, but there was wide variation from one pit to another in the rates for any particular occupation. A typical example is that of the eight collieries in Area *X* which had accident rates for coal-getters varying from 0·96 casualties per 1,000 shifts to 3·97. It was thought that this variation might be due in part to different habits of reporting minor injuries in the different pits. Using the classification of type of injury discussed above, the minor injuries (Type 1) were removed from the study but even so among the more serious injuries wide variation was still found between pits for each of the occupations.

Accidents were then analysed by cause for each of the occupations separately and it was found that, as might be expected, men in different occupations suffered accidents due to different causes. However, the pattern varied from pit to pit. On the other hand, the type of injury suffered did not appear to

vary from one occupation to another within each place of work; nor indeed did the type of injury vary clearly with the cause of the accident. This was found to be true for each place of work.

Finally, a study was made of the lengths of absence, and it was clear that, for similar types of injury, similar lengths of absence were taken, irrespective of what had caused the injury or whether the accident had taken place at the coalface or elsewhere underground. The lengths of absence for surface accidents could not be considered as the numbers of accidents in many categories were too small for their medians to be reliable. Table 5 illustrates the point for accidents occurring at the coalface.

TABLE 5

LENGTH OF ABSENCE BY CAUSE OF ACCIDENT AT COALFACE AND BY TYPE OF INJURY: DATA B

(Median length of absence in days)

Cause*	Type of Injury			
	1 (Slight)	2	3	4 (Serious)
Falls of roof, etc., at coalface	18	17	21	31
Machinery, etc.	16	16	16	42
Stumbling, etc.	17	16	17	24
Falling objects	18	15	15	40
Other causes	18	15	22	25

*Certain causes were excluded, because the numbers were too small to give reliable medians.

Thus the apparent differences in lengths of absence taken by coalface workers compared with other workers have been explained by differences in age distributions at the three places of work, and by the different types of injury suffered there. Nevertheless, it is clear from Table 3 that coalface workers suffer substantially more serious injuries (Types 3 and 4) than other workers. This might at first sight appear to be a contradiction of the observation that coalface workers have shorter absences on the whole than other workers. However, the figures in Table 6, summarized from the same data as Table 3, show that this is due to the even greater preponderance of " slight " injuries among coalface workers.

Thus for coalface workers there are 6·8 times as many slight injuries as serious ones, whereas for surface workers this ratio is only 3·5.

TABLE 6

CASUALTY RATES BY SEVERITY OF INJURY AND PLACE OF WORK: DATA A (1949)

(Number of casualties per man employed)

Type of Injury	Place of Work		
	Coalface	Elsewhere Underground	Surface
1 (Slight)	0·221	0·092	0·046
4 (Serious)	0·033	0·018	0·013
Ratio of slight injuries to serious injuries	6·8	5·3	3·5

Size of Colliery and Method of Raising Coal.—Using data C, a study was made of the effect of the size of colliery and the method of raising, by shaft or drift. Table 7 gives the mean accident rates and it can be seen that there is no clear indication that the underground accident rate increases with size of colliery, and it is obvious that surface rates are independent of the size of the colliery. The underground accident rate for drifts is lower than that for shafts, and it is possible that this accounts for some of the size effect found in other studies (Acton Society Trust, 1953; Paterson, 1956).

TABLE 7

ACCIDENT RATES BY SIZE OF COLLIERY AND METHOD OF RAISING: DATA C

(Number of casualties per hundred thousand manshifts worked)

Method of Raising	Size of Colliery (output in 1954)	Accident Rate	
		Underground	Surface
Shaft	Up to 99 thous. tons	132	53
	100 to 199 thous. tons	144	54
	200 to 349 thous. tons	152	56
	350 to 699 thous. tons	149	54
	700 thous. tons and over	155	50
Drift	Up to 99 thous. tons	113	60
	100 thous. tons and over	130	51

Miscellaneous Factors.—Data C were used to examine the suggestion that high surface accident rates are found where there are high underground rates and similarly that low surface and underground rates occur together. For this purpose the collieries were grouped according to whether their casualty rates were low, medium, or high. Table 8 shows the number of collieries which fall into each of the nine possible combinations of the groups of surface and underground rates. Shaft-raising collieries and drifts are considered separately.

Of the 163 shaft-raising collieries with a low underground accident rate, 97 (60%) also had a low surface rate. Similarly, 126 collieries (56%) of the 227 collieries with a high underground rate, also had a high surface rate. The pattern for drifts was similar.

It is therefore concluded that, over the country as a whole, there is a strong tendency for high accident rates to occur simultaneously on the surface and underground. Taking the divisions separately, the result was found to be true for shafts in five out of eight divisions and for drifts in all three divisions where they exist in substantial numbers. There is a strong tendency for all collieries with high underground accident rates to have high surface rates.

It was similarly found that collieries with a high underground accident rate in 1953 also tended to have a high rate in 1954.

Negative Results.—For data A, we attempted to study the effects of environment and of changes in mechanization, the times at which accidents occur, the effect of management, and accident experience near holidays. For the 14 collieries covered by data B a variety of descriptive information was taken from the colliery profile. This information included: Output of pit, productivity, depth of shafts, length of underground roadways, methods of mining, methods of underground transport, extent of mechanization, thickness of seams, extent to which shotfiring was employed, attendance, and supervision ratio.

Negative results were obtained in all these studies, probably because of the inadequacy of the data when considered from the particular point of view of this research rather than because the factors under examination were not important.

Conclusions

Although there was a vast quantity of data to be examined their quality was not high. Thus the research was basically a salvage operation—an attempt to obtain as much as possible from material collected for other purposes—and hence inevitably inadequate when considered from the point of view of research. In consequence, many of the results obtained either were negative or could be explained in terms of differences in habits, standards, and reliability of reporting.

It was noticeable, however, that where positive results did emerge from the study of data A, they were in general closely confirmed by the study of data B which was completely independent.

That we were unable to obtain many positive results is not surprising, but serves to emphasize that quantity is no substitute for quality. However, this is clearly not always appreciated as the statistician is often approached with the statement: " I have so much material it must be useful."

We conclude that there is a need for a study of the method of recording accidents at collieries to determine whether the recording which is necessary as a routine can be adapted to provide material for research purposes. As the recording of statutorily reportable casualties is reasonably reliable, statistical examination of the records of such accidents should be profitable. These studies are in fact being sponsored by the Medical Service of the National Coal Board, and special report forms were introduced for reportable accidents occurring in 1957. The Medical Service also sponsored a project being carried out by the Department of Experimental Psychology of the University of London. Here detailed reports were collected in a group of collieries for every reported casualty over a period of a year. This should also cast some light on the methods of recording, and will, of course, be complementary to the study of reportable accidents.

Summary

This report describes the results of work on three bodies of data, relating to accidents at collieries. The data were:

A: Basic data relating to each compensable casualty occurring at each of the 900 odd collieries in Great Britain during the five years 1945 to 1949.

B: More detailed data relating to each compensable casualty occurring at 14 particular collieries in the year 1953.

C: Compensable casualty rates and background information for each of the 900 odd collieries for 1953 and 1954.

From an examination of published figures it appears that, although the rates of fatal and " reportable " casualties probably reflect the degree of safety enjoyed by collieries, the rates of compensable casualties do not. Data A, B, and C all concern compensable casualties, and we have found in these data a substantial body of evidence that there are marked differences in habits of reporting and standards of recording. There were, therefore,

TABLE 8

NUMBERS OF COLLIERIES GROUPED BY UNDERGROUND AND SURFACE ACCIDENTS RATES: DATA C

Method of Raising	Surface Accident Rate Casualties per 100,000 Manshifts	Underground Accident Rate Casualties per 100,000 Manshifts			Total
		Low Rate (Up to 125)	Medium Rate (126 to 155)	High Rate (156 and over)	
Shaft	Low rate (up to 39)	97	79	27	203
	Medium rate (40 to 62)	49	92	74	215
	High rate (63 and over)	17	51	126	194
	Total	163	222	227	612
Drift	Low rate (up to 39)	52	23	6	81
	Medium rate (40 to 62)	24	19	9	52
	High rate (63 and over)	25	24	40	89
	Total	101	66	55	222

few positive results but those which were obtained with data A and B were in close agreement.

Casualty rates were found to decrease with age, but this effect was mainly for the less serious injuries. In other words, the incidence of serious injuries did not depend on age, but younger men had more of the milder type of injury than their elders. After an injury, men over 50 were off work for rather longer than men of 21 to 50. When men under 21 suffered serious injury they took as long to return to work as men over 50, that is, much longer than their immediate elders in the 21 to 30 group.

It was found that casualty rates were always highest among coalface workers, with rates for workers elsewhere underground next, and surface workers' rates lowest. On the other hand, coalface workers had the shortest absences, because they had a high proportion of slight injuries which led to short absences. This high proportion of slight injuries, and the short absences resulting from them, tended to obscure the important finding that coalface workers also had about twice as many serious injuries as other workers. Apparent differences in lengths of absence between workers in the different places could be fully accounted for in terms of age and nature of injury. No particular occupational groups within the main places of work seemed to be substantially different in their accident experience.

There was no clear indication that underground accident rates increased with the size of colliery, but it was found that drifts, which were predominantly small, had lower accident rates than collieries of a similar size raising by shaft.

A strong tendency was found for collieries with high underground accident rates to have high surface rates, and *vice versa*. Similarly, the accident rate in a colliery appeared to be relatively stable from one year to another.

Studies of other factors did not lead to positive conclusions, probably on account of the inadequacy of the data.

We wish to acknowledge the help of all those concerned in this investigation, and in particular of Dr. J. M. Rogan, Chief Medical Officer, and Mr. R. F. George, Chief Statistician, of the National Coal Board.

The views expressed in this paper are our own and not necessarily those of the Board.

References

Acton Society Trust (1953). *Size and Morale*. London.
Liddell, F. D. K. (1955). *J. roy. Stat. Soc. A.*, **118**, 405.
Ministry of Power (1957). *Statistical Digest*, 1956. H.M.S.O. London.
Paterson, T. T. (1956). *Operat. Res. Quart.*, 7, 155.

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ASEPTIC NECROSIS OF BONE IN CAISSON DISEASE

BY

JOHN D. THOMSON and ANDREW B. YOUNG

From the Royal Infirmary, Glasgow

(RECEIVED FOR PUBLICATION MAY 17, 1958)

Caisson disease, or decompression sickness, is encountered when a raised atmospheric pressure on the body is reduced too rapidly and excess gases which have been held in solution in the blood and tissue fluids are set free as their solubility decreases. Typically the condition is manifested by tingling and paraesthesia, itching of the skin, and by bone and joint pains. The symptoms vary within wide limits, the majority being of a mild nature and in most instances relief is obtained by prompt recompression. The fact that permanent changes can take place in bone has, however, been recognized for some time. Twynam (1888) reported a case of necrosis of the shaft of the femur. Bassoe (1913) and Kahlstrom, Burton, and Phemister (1939a) described degenerative joint lesions with adjacent bony infarcts.

Such lesions are not common. Ronald (1953) described infarcts involving the lower end of both femora, the upper end of both tibiae, and both humeral heads in a man who had been working as a diver for some 40 years. McCallum, Stanger, and Walder (1954) reported a case of necrosis of the femoral head in a caisson worker engaged in the construction of the Tyne tunnel. In reviewing the literature they found only two reports from Great Britain of bone infarction following decompression. One was in a caisson worker who died of acute cardiac ischaemia and at necropsy was found to have an avascular necrosis of both humeri (Swain, 1942). In the second report James (1945) gave an account of his findings in three of the five survivors of the ill-fated H.M. submarine *Poseidon* which sank after a collision in 120 ft. of water in 1931. The survivors escaped by use of the Davis apparatus and suffered in varying degree from " bends " immediately or shortly after surfacing. When examined 12 years later one had a lesion of the left humeral head, another had both femoral heads involved, while the third had an infarct of the left hip and left shoulder. In view of the rarity of this complication of caisson disease the following case may be of interest.

Case Report

The patient first worked under increased atmospheric pressure in 1954. At that time he was employed in the building of a power station and in the course of five weeks had occasion to enter the pressure chamber about twice a day for periods of about 10 minutes each time. The pressure inside the chamber was 32 lb./sq. in. On each occasion the patient himself controlled the decompression, judging the rate by the feeling in his ears. He suffered no ill effects at this time.

In July, 1955, the patient was again employed in the caisson. He states that for five days he worked a shift of 12 hours at a pressure of 15 lb./sq. in., being allowed out of the chamber for two 20-minute periods each day. Decompression was controlled by the shift workers themselves. After a break of 48 hours the patient began work again on an eight-hour shift, the pressure having been increased to 20 lb./sq. in. Meals were taken inside the chamber. About three hours after this shift and while lying in bed, he was suddenly seized by severe pains in both upper arms, both hips, the right knee, and the right mastoid area. The pains came on instantaneously, were deep and boring in character and almost unbearable in their severity. With the aid of codeine tablets the pain became less severe and as his job at this time was not heavy, he was able to continue with his regular work in the caisson for two more days. By that time the pains had almost disappeared from everywhere except the right hip, but because of its crippling nature, he was forced to stop work. Over the next week the pains disappeared completely from the other areas but persisted in the right hip. During the next two years the patient was employed intermittently on a number of light jobs, but became increasingly crippled by the pain in the right hip, and the apparent weakness of the right leg.

Examination.—The patient is a strongly built man of 37 years of age. He walked with a slight protective limp on the right side, taking his weight on the ball of the foot. Posture was good and there was no spasm of the erector spinae. Forward flexion of the spine was limited by 25%, but other spinal movements were free. There was

obvious gluteal wasting on the right side and the Trendelenburg hip test was weakly positive on that side. Visible wasting of the right quadriceps was present and proved on measurement to be 1 inch. Movements of the right hip were all restricted; flexion 100°, internal rotation 15°, external rotation 15°, abduction 15°, adduction 15°. There was weakness of the right knee jerk, but no other abnormal neurological finding. General examination revealed no significant abnormality, and other joint movements were free.

Blood examination gave the following results:

Plasma inorganic phosphorus = 4·1 mg. per 100 ml. (2·4 mEq./litre), serum calcium = 11 mg. per 100 ml. (5·5 mEq./litre), plasma alkaline phosphatase = 1·2 Bodansky units. A radiograph of the right hip (Figs. 1 and 2) showed a sclerotic area involving the inferior aspect of the head and upper part of the neck of the right femur, consistent with the appearances of avascular necrosis. The radiographic appearances of the shoulders, knees, and left hip were normal.

Discussion

At present there does not appear to be any agreement on the precise pathogenesis of avascular necrosis in caisson disease. Of the gases released on decompression, oxygen is readily utilized and carbon dioxide is exhaled through the lungs. The excess nitrogen is not disposed of so readily; it tends to accumulate in the tissues of the central nervous system or in the marrow of bone where the lipoid and fat content are high. Nitrogen emboli in the vessels of the epiphysis have been held by some (Colonna and Jones, 1948) to be the cause, but others (Kahlstrom *et al.*, 1939a) doubt if this is so. Kahlstrom *et al.* (1939b) were unable to reproduce the lesion experimentally in animals. It seems reasonable that the infarct may be due to an accumulation of nitrogen at a particular site in bone causing local ischaemia by pressure on vessels. An additional factor suggested by End (1938) is that external pressure tends to increase the intravascular agglutination of erythrocytes, thereby leading to a local thrombosis of the smaller vessels. The bone lesions, by their nature, may be silent, especially if they

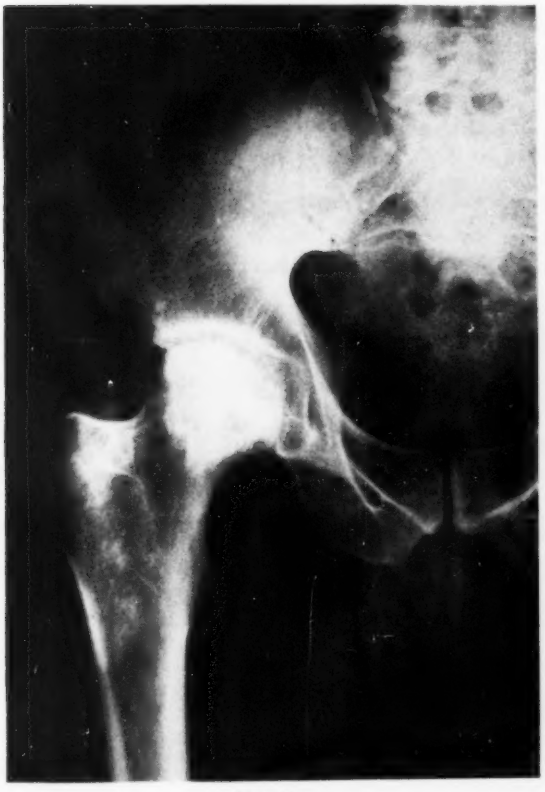

FIG. 1

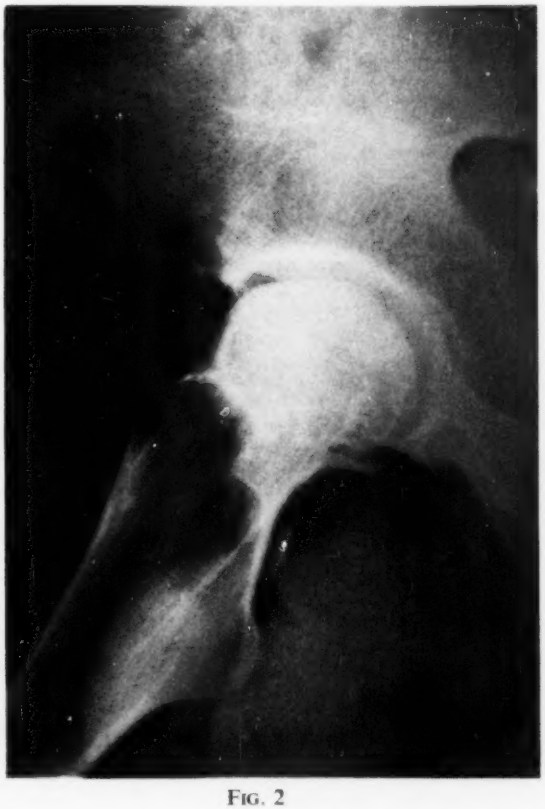

FIG. 2

FIGS. 1 and 2.—Radiographs of right hip, showing extensive destruction of the head and upper inferior aspect of the neck of the femur, with surrounding sclerosis.

occur in the shafts (Coley and Moore, 1940). In our case it is interesting to note that the pain of " bends" was most noticeable in the region of the right hip and it remained at that site after recompression and persisted after the other pains had gone. It seems probable that more frequent radiographs of the bony parts involved would lead to an earlier recognition of the lesion and to a more accurate assessment of its incidence.

We should like to express our thanks to Mr. P. Kelly for his reproduction of the radiographs.

References

Bassoe, P. (1913). *Amer. J. med. Sci.*, **145**, 526.
Coley, B. L., and Moore, M. (1940). *Ann. Surg.*, **111**, 1065.
Colonna, P. C., and Jones, E. D. (1948). *Arch. Surg. (Chicago)*, **56**, 161.
End, E. (1938). *J. industr. Hyg.*, **20**, 511.
James, C. C. M. (1945). *Lancet*, **2**, 6.
Kahlstrom, S. C., Burton, C. C., and Phemister, D. B. (1939a). *Surg. Gynec. Obstet.*, **68**, 129.
——, ——, —— (1939b). *Ibid.*, **68**, 631.
McCallum, R. I., Stanger, J. K., and Walder, D. N. (1954). *J. Bone Jt Surg.*, **36b**, 606.
Ronald, J. (1953). *Lancet*, **2**, 855.
Swain, V. A. J. (1942). *Brit. J. Surg.*, **29**, 365.
Twynam, G. E. (1888). *Brit. med. J.*, **1**, 190.

THE JULY (1958) ISSUE

The July (1958) issue contains the following papers:—

The Accuracy of Occupational Vital Statistics. By M. A. Heasman, F. D. K. Liddell, and D. D. Reid.

The Influence of Clothing on the Pattern and Severity of Burns Studied in Some Recent Colliery Fire-damp Ignitions. By M. N. Tempest and J. B. Atkins.

The Toxic Properties of Demeton-methyl (" Metasystox ") and Some Related Compounds. By M. Vandekar.

Tissue Reactions Produced by Calcium Fluoride in the Lungs of Rats. By E. J. King, M. Yoganathan, and G. Nagelschmidt.

The Tissue Reaction in the Lungs of Rats after the Inhalation of Coal Dust Containing 2% of Quartz. By E. J. King, S. Zaidi, C. V. Harrison, and G. Nagelschmidt.

Pneumoconiosis of Coal-miners in Three Northumbrian Collieries. By R. I. McCallum and D. J. Newell.

Industrial Dermatitis in the Coal-miner. By O. P. Edmonds.

Lesions of the Skin in Process Workers Caused by Contact with Butyl Tin Compounds. By W. H. Lyle.

Climate and Health in the Royal Navy. By F. E. Smith.

The Emotional Stability of Miners with Nystagmus. By Judith S. Lion.

A Case Illustrating the Effect of Calcium Disodium Versenate ($CaNa_2E.D.T.A.$) on Chronic Mercury Poisoning. By S. M. Woodcock.

A Case of Beryllium Disease. By C. H. Wood, K. P. Ball, and N. Donald Teare.

Book Reviews.

A number of copies are still available and may be obtained from the Publishing Manager, British Medical Association, Tavistock Square, W.C.1, price 17s. 6d.

Brit. J. industr. Med., 1958, **15**, 273.

SOME NOTES ON THE EFFECTS OF EXCESSIVE NOISE ON THE HEARING OF A GROUP OF WORKERS*

BY

G. F. KEATINGE and S. LANER

From the Medical Department, the Butterley Company Limited, Ripley, Derby, and the Operational Research Department, the British Iron and Steel Research Association, London

(RECEIVED FOR PUBLICATION AUGUST 3, 1957)

The data for the present investigation were collected between August, 1951, and August, 1956, in the Butterley Company's works at Codnor Park. In some of the shops of these works the noise is so intense that outsiders experience it as unpleasant and in some spots even as unbearable. During the period mentioned no protective devices were in use, largely because the workers found many of the existing protectors both uncomfortable and otherwise inconvenient.

The availability of audiometric records of workers who had been exposed to noise for periods from one year to seven years made possible a first attempt to relate deterioration in hearing to prolonged exposure to intense intermittent noise. That such deterioration (based on permanent and irreversible changes in the auditory organs) occurs is well known. But the relationship between length of exposure and loss is somewhat complicated by the fact that a certain amount of loss is brought about by the natural process of ageing (presbycusis).

Measurement of Noise

To assess the overall level of ambient noise in the three shops where it appeared to reach maximum intensity, measurements were taken by means of the Dawe sound level meter, Type 1400D. The maximum readings are shown in Table 1. Samples of the noise measured were simultaneously recorded on tape for subsequent frequency analysis.

Shop No. 3 is a large building, of which the walls are partly of brick and partly of corrugated iron; the roof is of asbestos. The reverberation effects in the shop are considerable. Most of the workers on the shop floor are engaged more or less directly in the riveting of wagon undercarriages, the operatives most immediately exposed to noise being the riveter himself and the holder-up who maintains the steel rivets in place. The sound meter here, and for all other measurements, was placed at a distance from the noise source approximating to the usual distance of the operative from it.

TABLE 1

MAXIMUM READINGS OF NOISE IN THREE SHOPS

Site	Placing of Meter	Maximum Reading (in Decibels)
Shop No. 3	Beside riveter	115
Shop No. 7	Outside aluminium trough	122
Shop No. 7	Inside aluminium trough	128
Shop No. 1	Beside riveter	116

In Shop No. 7 large aluminium troughs, used ultimately as superstructures for pit trams or trolleys, are riveted. The noise was measured both outside the trough, *i.e.*, at the position taken up by the riveter, and inside it, where the holder-up keeps the rivet in place.

Shop No. 1 is similar to Shop No. 3 in layout and in the operations carried out. A spot check taken at a distance of 10 yards from the noise source in a bay of Shop No. 1 gave a reading of 102 db.

Table 2 shows the frequencies at which the noises measured reached their peak intensities.

TABLE 2

PEAK INTENSITIES OF MEASURED NOISE

Site		Peak Intensity (c./sec.)
Shop No. 3	Recording 1	1,500-2,000
	Recording 2	1,500-2,000
Shop No. 7	Recording 1	1,000-1,500
	Recording 2	1,500-2,000
Shop No. 1		1,500-2,000

The noises recorded all reached their peak intensities at frequencies at which with prolonged exposure they are likely to produce damage attended by loss of hearing.

Hearing Tests

The assessment of the hearing of the workers was carried out by pure tone audiometry and the loss of hearing at the frequencies of 128, 256, 512, 1,024, 4,096, and 8,192 cycles per second was recorded by the method

*Read before a joint meeting of the Ergonomics Research Society and the British Occupational Hygiene Society, held in London on June 28, 1957.

AUDIOGRAM AND HEARING LOSS CHART.

(PREPARED BY EDMUND P FOWLER, M.D. AND P.E. SABINE, PH.D.)

NAME _____ AGE _____ NO. _____

ADDRESS _____ DATE _____

HEARING LOSS IN DECIBELS

128	256	512	1024	2048	4096	8192
0						
10		·2	·3	4	·1	
		·5	·9	1·3	·3	
20		1·1	2·1	2·9	·9	
		1·8	3·6	4·9	1·7	
30		2·6	5·4	7·3	2·7	
		3·7	7·7	9·8	3·8	
40		4·9	10·2	12·9	5·0	
		6·3	13·0	17·3	6·4	
50		7·9	15·7	22·4	8·0	
		9·6	19·0	25·7	9·7	
60		11·3	21·5	28·0	11·2	
		12·8	23·5	30·2	12·5	
70		13·8	25·5	32·2	13·5	
		14·6	27·2	34·0	14·2	
80		14·8	28·8	35·8	14·6	
		14·9	29·8	37·5	14·8	
90		15·0	29·9	39·2	14·9	
			30·0	40·0	15·0	
100						

OCTAVE FREQUENCIES

PER CENT HEARING LOSSES

	RIGHT EAR	LEFT EAR
512		
1024		
2048		
4096		
TOTAL		

COMPUTATION OF PER CENT LOSS OF CAPACITY TO HEAR SPEECH

(A) 7 X TOTAL PER CENT LOSS, BETTER EAR

(B) 1 X TOTAL PER CENT LOSS, WORSE EAR

(C) SUM (A)+(B)= _____

(D) PER CENT BINAURAL LOSS. C ÷ 8 _____ %

RECORDED BY _____

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INSTRUCTIONS: PLOT THE HEARING LOSSES BY AIR CONDUCTION FOR EACH EAR AT THE FOUR FREQUENCIES SHOWN, AND CONNECT CONTIGUOUS POINTS BY STRAIGHT LINES. THE PER CENT LOSS ASSIGNED TO EACH OCTAVE INTERVAL IS THE FIGURE IMMEDIATELY ABOVE THE HORIZONTAL LINE. SET DOWN THESE FIGURES IN THE FOUR SPACES UNDER RIGHT AND LEFT EAR, IN THE COLUMNS TO THE RIGHT OF THE CHART. ADD EACH COLUMN AND COMPUTE THE BINAURAL PER CENT LOSS OF CAPACITY TO HEAR SPEECH, AS INDICATED.

FIG. 1

described by Fowler (1947), in which the decibel grading of the audiogram is supplemented by percentage ratings of loss of hearing o the sounds of normal speech, which are principally in the band 512-4,096 cycles per second. Since the sounds falling into the narrower band of 1,024 to 2,048 cycles per second are the most important for interpreting speech and losses in these frequencies are thus more serious, they are given higher loss percentage ratings. The special chart (Fig. 1) makes it possible to obtain an average loss percentage rating for hearing speech for both ears (binaural loss).

The tests were undertaken in a quiet room in the works surgery which is situated approximately 50 yards from the nearest workshop. Admittedly there was some background noise, but all the tests were carried out by the same tester under the same conditions and can thus reasonably be compared with each other. None of the workers suffered from chronic ear disease in any form. All had the ears examined before testing and if cerumen was found, it was removed, and the hearing tested two days later.

Exposure Period and Hearing Loss

Two straightforward measures were taken to control factors which might otherwise have vitiated the results of the attempt to relate length of exposure to noise with loss of capacity to hear speech.

To eliminate the complicating factor of hearing loss due to ageing, the rate of which increases steeply after the age of 40, the audiograms of all workers of and above this age were excluded from the analysis.

Secondly, audiograms were obtained for a control group of 20 subjects, consisting of new starters and others who had never been exposed to intense noise for any appreciable length of time. The audiometric procedure was carried out in the same room by the same tester who had tested the experimental subjects. The obvious purpose of having a control group was to provide a base line: the loss percentages obtained for members of the control group cannot be ascribed to exposure to intense noise and are probably due in the main to ambient noise in the test chamber.

Table 3 gives the mean percentage of binaural loss of hearing of speech for each exposure group. The second column (N) shows the number of audiograms on which the mean value is based.

Inspection of the third column in Table 3 suggests at first that hearing loss is a direct function of the exposure period, but this consistent trend is broken by the group with the longest exposure period.

Statistical treatment showed that increases (or

TABLE 3

MEAN PERCENTAGE LOSS OF HEARING OF SPEECH FOR EACH GROUP

Period of Exposure	N	Mean Hearing Loss (%)	Difference between Adjacent Means
No exposure: (control group)	20	15·7	
			+6·6*
1 year	7	22·3	
			+4·9*
2 years	7	27·2	
			+7·6*
3 years	8	34·8	
			+2·0
4 years	14	36·8	
			+1·8
5 years	11	38·6	
			−6·0*
6 and 7 years ..	16	32·6	

decreases) in hearing loss as large as or larger than those marked by an asterisk, could occur by chance only five times in a hundred. This means that, in so far as the results obtained are representative of the position in general, during the first three years impairment in the capacity to hear speech proceeds at an appreciable rate, possibly reflecting a concomitant rate of damage to the auditory apparatus. The decrease in the rate of impairment after three years' exposure, and the reversal in impairment for the six and seven years' exposure group suggests that exposure for three years caused so much damage that a ceiling was reached; to test this hypothesis a much larger volume of data would be needed.

The practical implications of this analysis are that anti-noise protective devices may have their maximum effectiveness if introduced to people at the start of their employment on noisy jobs: that they can still be of considerable effectiveness if introduced during the first, second, and third years of exposure; and that the value of using them after three years of uninterrupted free exposure to intense noise has either gone or is in doubt.

Effect of Age

As individuals with longer exposure are, as a rule, also older, the possibility that greater hearing loss in each successive exposure group might have been due at least in part to the higher age of its members was examined. Apart from the gross obtrusion of presbycusis which was eliminated by excluding the records of those aged 40 and over, it seemed wise to scrutinize the remaining records for any consistent trend indicating hearing loss due to ageing rather than to exposure.

The available data made it possible to calculate the regression of hearing loss on age, or, in other words, to " measure " the magnitude of any trend due to ageing. This trend is expressed in the test ratio in the summary of the regression analysis in Table 4.

TABLE 4

SUMMARY OF REGRESSION ANALYSIS

Source of Variation	Degrees of Freedom	Mean Squares	Test Ratio
Regression of hearing loss on age	1	21·9	0·11
Residual variation	81	207·7	

It can be shown that a trend as high as or higher than that measured by the above test ratio would be expected to occur by chance with a probability of 0·4. This means that no consistent effect of age differences on hearing loss was apparent in our data.

Summary

Measurements at three shops of the Butterley Company, Codnor Park Works, suggested that the ambient noise might reach levels deleterious to hearing. Frequency analysis showed that the noise reached its peak in the band critical for speech perception.

Analysis of the audiometric records of workers under 40 years of age exposed to this noise continuously for periods from one to seven years suggested that the initial exposure period of up to three years is attended by the greatest hearing loss.

After the first three years' exposure the rate of deterioration appeared to slow down or possibly even to cease.

It is suggested that protective devices may be optimally effective if introduced at entry into the job or soon afterwards.

More data are needed to test the hypothesis that after three years' exposure no further deterioration occurs, the damage previously sustained having possibly reached a ceiling.

The authors are indebted to the workers at the Butterley Company Limited for their ready cooperation when measurements were taken. Thanks are also due to Mr. W. G. R. Hore, surgeon in the Ear, Nose, and Throat Department of the Derbyshire Group of Hospitals, for advice and help in the technique of audiometry and in the interpretation of audiograms: and to Mrs. E. R. Buxton, nursing sister in charge of the surgery at the Codnor Park Group of Works of the Butterley Company Limited, for much help in the organization and in the carrying out of these tests.

REFERENCE

Fowler, E. P. (1947). *Laryngoscope (St. Louis)*, 57, 103.

Brit. J. industr. Med., 1958, **15**, 276

AN INVESTIGATION OF SOME HEALTH HAZARDS IN AN INERT-GAS TUNGSTEN-ARC WELDING SHOP

BY

P. J. R. CHALLEN, D. E. HICKISH, and JOAN BEDFORD

From the Slough Industrial Health Service

(RECEIVED FOR PUBLICATION DECEMBER 7, 1957)

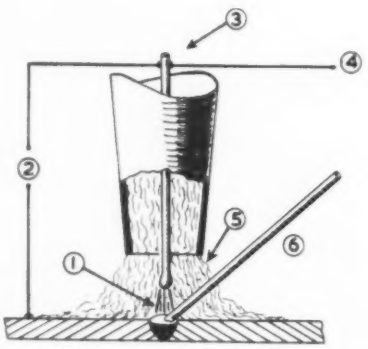
Inert-gas Arc Welding of Aluminium

Aluminium is used widely in metal fabrication processes, chiefly on account of its lightness, the ease with which it may be cast, and its extreme ductility. It is also highly resistant to corrosion, owing to the formation of a protective film of oxide on the surface of the metal. This latter property, however, becomes a disadvantage when it is desired to weld the metal, as the oxide film hinders consolidation of the metal on fusion, and even when broken down it re-forms almost instantaneously in air. Aluminium may be welded by either gas or arc processes, but arc welding is more satisfactory as the area over which the heat is generated is smaller and the speed of welding can thus be increased. The thermal conductivity of aluminium is high, being five times greater than that of steel, and hence with arc welding distortion and any tendency to crack are reduced.

With both gas and arc welding the oxide may be dispersed by means of fluxes, but the disadvantage of this procedure is that the flux residues are corrosive, and after completion of the weld thorough cleaning of the metal is essential. Joints have thus to be so designed as to avoid trapping flux.

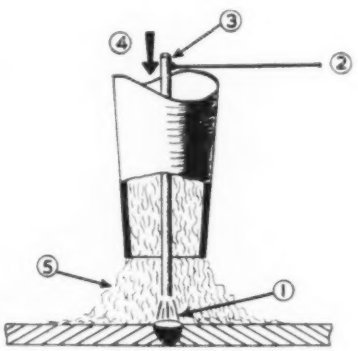
These problems have led to the development of forms of arc welding which utilize an inert-gas arc shield, usually of argon or helium. This gas shield allows the arc to disperse the oxide film, and by the exclusion of oxygen prevents it from being reformed. The use of these welding methods gives greater freedom in design, and the welding torch may even be used to form a weld inside a partly sealed container. As these welding methods are capable of automatic operation higher welding speeds may be achieved, and this feature, together with the use of higher welding currents than are employed in manual welding, enables welding to be carried out on thicker metal than would otherwise be the case.

Two main types of inert-gas shielded welding are used, and are shown diagrammatically in Figs. 1*a* and 1*b*. The inert-gas tungsten-arc method (Fig. 1*a*) uses a non-consumable tungsten electrode for producing the arc, and the welding is normally carried out by the use of a filler rod of aluminium.



(*a*)

1—Welding arc
2—Surge injection (if used)
3—Tungsten electrode
4—A.C. or D.C. supply, H.F. impulses superimposed
5—Shielding gas, usually argon, but mixtures with small quantities of other gases may be used
6—Filler wire



(*b*)

1—Welding arc
2—D.C. supply
3—Consumable electrode wire
4—Wire feed
5—Argon or CO_2 shielding gas

FIG. 1.—Diagram of inert-gas arc-welding apparatus.
(*a*) Inert-gas tungsten-arc welding.
(*b*) Inert-gas metal-arc process.

FIG. 2.—General view of the welding shop.

A proportion of the parent metal may be melted into the weldbead, and this may affect the weld properties. The arc temperature is normally about 5,000° C.

A development of this method utilizes a consumable electrode in place of the tungsten electrode, and is known as the inert-gas metal-arc welding process (Fig. 1*b*). The electrode is in the form of a wire which is coiled on a reel and passes through the conduit which conducts argon gas to a welding gun. The trigger of the gun operates both gas and electrical controls. Very high current densities, of the order of 100,000 amps./in.^{2} are used, and hence a smooth steady arc is produced and welding in the vertical or overhead positions is possible.

The current densities used in this type of welding are greater than normally encountered with ordinary stick electrodes, and a more confined source of spectral energy in both ultra-violet and infra-red ranges is produced. Whereas the spectral emission from the iron arc is principally in the blue and near visible range, that from aluminium is principally below 3,900 Å, and the bulk of the radiation is concentrated in a few lines. This factor is of considerable importance from the point of view of industrial hygiene, as it is the radiations having wavelengths between 1,750 and 2,500 Å which act upon air to produce ozone. Argon also has strong emission spectral lines at 1,850 Å. Helium is sometimes used for the gas shield, and with this gas less ozone is produced than with argon (Ferry and Ginther, 1952). The absence of rod coatings, which are commonly employed in ordinary arc welding, means that very much less fume is produced, and there is therefore less absorption of ultra-violet radiation by the fume. By the use of an electrode in the form of a continuous coil of wire, the process may be used for longer periods than would be possible in ordinary arc welding. The welding of non-ferrous metals requires that the metal surfaces shall be free from grease, and it is common for trichloro-ethylene degreasing of the component parts to precede the welding operation.

Environmental Survey

Procedure.—The investigation to be described was the outcome of an enquiry sent to our laboratories by the management of a firm manufacturing aluminium milk churns. The sister in charge of the Works Medical Department had noticed that workers in the welding shop were frequently complaining of upper respiratory symptoms, and she suspected that these complaints might be the result of exposure to phosgene. On inspecting the process, however, we considered that the main atmospheric contaminant was probably ozone, the odour of which was readily discernible in the welding shop. The welding shop concerned had a low ceiling, was crowded with machinery, and the adequacy of the general ventilation was doubtful.

The firm has designed a series of automatic welding machines embodying a modification of the inert-gas tungsten-arc process. The aluminium components are placed in a jig, and an arc is struck between the tungsten electrode and the edges to be joined. With this type of machine no filler rod is required, and the metal for the weld is obtained by fusion of the edges of the components themselves. A general view of the welding shop is shown in Fig. 2, and a close-up view of one of the automatic welding machines in Fig. 3. Before welding, all the parts are degreased in a trichloro-ethylene tank in an adjacent bay, which communicates with the welding shop through an open doorway. A preliminary investigation, in collaboration with Mr. R. J. Sherwood, revealed concentrations in the welding shop of up to 1·07 p.p.m. of ozone and up to 69 p.p.m. of

trichloro-ethylene. This finding led us to consider further the possibility of phosgene formation, and in the present investigation air samples were analysed for ozone, trichloro-ethylene, and phosgene.

Trichloro-ethylene was collected on silica gel (Hickish, Smith, and Bedford, 1956) and analysed by the Volhard method (Elkins, 1950). Ozone was collected in fritted glass bubblers containing potassium iodide solution and analysed by an iodometric method. It was appreciated that this method was not specific for ozone, and that nitrogen-oxides would interfere, but we were aware of the work of Kleinfeld, Giel, and Tabershaw (1957) which indicated that significant concentrations of oxides of nitrogen were absent during inert-gas shielded metal arc welding and that ozone was the principal hazard. The presence of phosgene was determined by a modification of the D.S.I.R. method (Department of Scientific and Industrial Research,

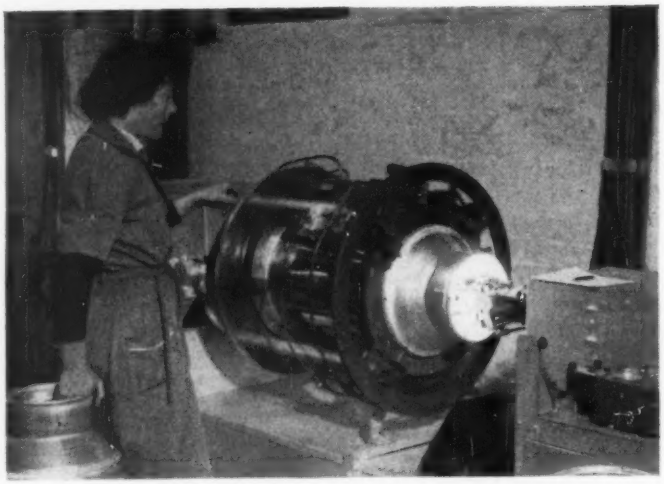


FIG. 3.—Close-up view of a typical automatic welding machine.

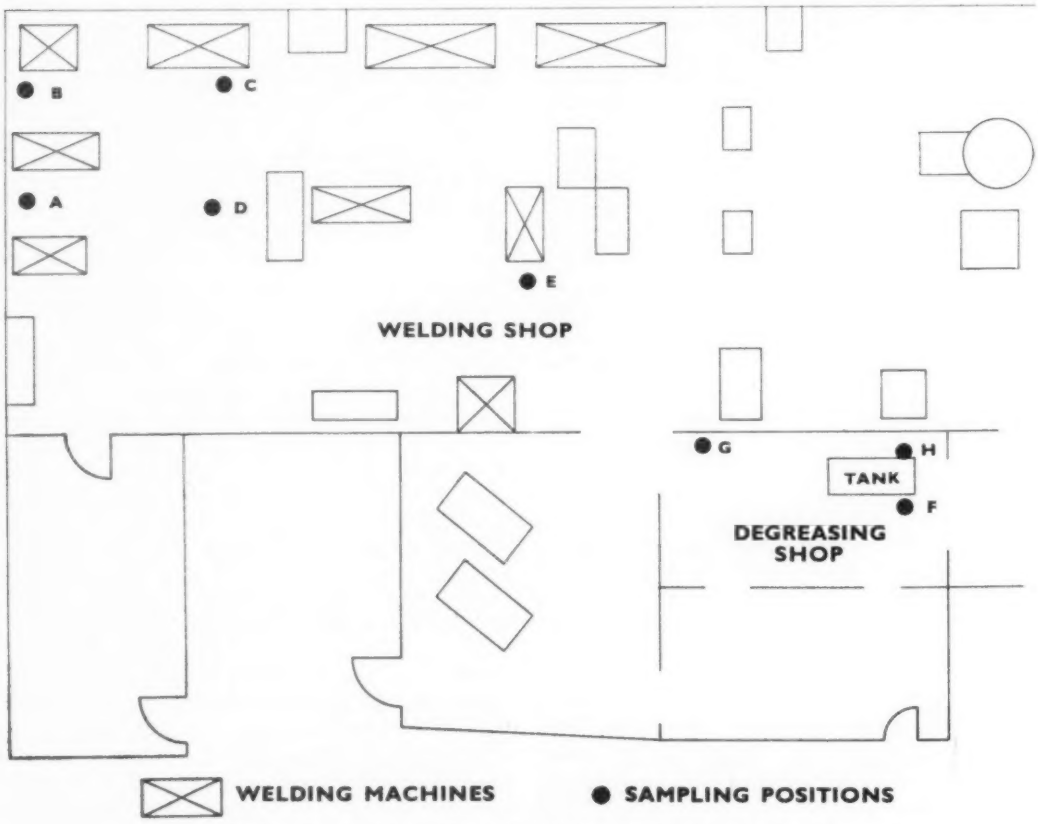


FIG. 4.—Plan showing sampling positions in the welding and degreasing shops.

1939), an electric pump sampling at the rate of 1 litre/min. being used in place of a hand-pump. The determination of small quantities of phosgene in the presence of larger quantities of trichloro-ethylene was achieved by a method which was suggested to us by the Chemical Defence Experimental Establishment at Porton. Samples were collected in Neale bubblers containing 5 ml. of an aqueous solution of caustic soda and hexamine, and were subsequently titrated electrometrically with silver nitrate solution. The method had previously been calibrated in our laboratories against standard concentrations of phosgene set up in a 45-cu. ft. calibration chamber. We confirmed that the addition of 200 p.p.m. of trichloro-ethylene to the phosgene concentration did not affect the analysis.

All the air samples were collected in the breathing zone of the workers over periods of approximately 30 minutes at five operating positions in the welding shop and at one position (F marked on Fig. 4) in the degreasing shop. It was arranged that freshly degreased components would be used during the collection of samples 5 and 6 in order to assess the resulting air contamination from this method of working—probably the severest conditions likely to be encountered. The location of the sampling positions, and those described below, is shown in Fig. 4.

On a subsequent occasion further air sampling for trichloro-ethylene was carried out in the degreasing shop, which was situated adjacent to the welding shop. The degreasing tank was of the vapour phase type, and was provided with covers. Three sampling positions were selected as follows: Position F, breathing zone of the operator; Position G, adjacent to the doorway between the degreasing and welding shops, thus giving an indication of the concentrations of vapour which could be conveyed to the welding shop under certain conditions of ventilation; Position H was 12 in. above the tank edge level at the rear of the tank, and was selected to enable a study to be made of the usefulness of the tank covers.

Sampling was repeated under three different operating conditions, as follows:

Run 1.—The tank was operated with the covers open. The doors and windows of the degreasing shop were closed, but normal natural ventilation was provided in the welding shop.

Run 2.—The tank was operated with the covers open, and maximum natural ventilation was provided in both degreasing and welding shops.

Run 3.—The tank was operated with the covers closed during degreasing, ventilation conditions being as for the first run.

Results.—The results of the air sampling in the welding shop, and of the single sample taken in the degreasing shop are shown in Table 1, which also includes the maximum allowable concentrations for trichloro-ethylene, ozone, and phosgene recommended by the American Conference of Governmental Industrial Hygienists (1956). The figure for ozone is further discussed below.

The filter paper test for phosgene (Department of Scientific and Industrial Research, 1939) gave only a pale cream discoloration with samples of several litres of air, thus indicating the presence of only a trace of phosgene. The colour produced was slightly deeper near the machines where freshly degreased parts were used.

Trichloro-ethylene concentrations found in the degreasing shop are shown in Table 2.

TABLE 2
TRICHLORO-ETHYLENE CONCENTRATIONS IN DEGREASING SHOP

Run	Position	Trichloro-ethylene* Concentration (p.p.m.)
1	F	266
	G	230
	H	412
2	F	247
	G	84
	H	466
3	F	184
	G	101
	H	472

*M.A.C. = 200 p.p.m.

TABLE 1
RESULTS OF AIR ANALYSIS IN WELDING SHOP

Sample	Position	Trichloro-ethylene (p.p.m.)	Ozone (p.p.m.)	Phosgene (p.p.m.)	Remarks
1	A	0	1·4	Less than 0·1	
2	B	8	0·8	,,	
3	C	1	0·9	,,	
4	D	3	1·7	,,	
5	A	97	1·2	,,	One machine using freshly degreased parts
6	E	13	0·9	,,	Adjacent machine using freshly degreased parts
7	F	238	—	,,	Degreasing shop
Maximum allowable concentration		200	0·1	1·0	American Conference of Governmental Industrial Hygienists (1956)

Clinical Survey

When the clinical survey began, automatic welding machines had been in use for three and a half years but had only been installed in the workshop under investigation for two and a half years. The firm employed some 190 workers and 50 staff and had increased its output by the introduction of automatic production methods to 2,000 churns per week, yet it was still unable to supply the demand.

So as to disrupt workshop organization as little as possible it was decided that employees would be interviewed but not examined or subjected to laboratory tests unless there was a clear indication in any case for these procedures. It was also decided to restrict the interviews to those employees who operated the welding machines, as the firm's nursing sister informed us that the other employees in the workshop had not complained to her of any symptoms.

Fourteen employees (11 female and three male) were therefore interviewed out of a labour force of 36 (17 female and 19 male) in the workshop. The ages of the 11 female employees ranged from 21 to 50 and the length of time they had been welding from one to 30 months; the three male employees were aged 41, 37, and 34 years, and two had been welding for 24 months, the other for a period of 42 months. Only three out of the 14 employees had been free from symptoms during their period of exposure. The others were troubled periodically and complained of a dry mouth and throat, irritation of the nose and eyes, and lacrimation. Eight objected to a " disagreeable " smell which they could not describe more accurately, and which they stated was often present in the early morning on starting work. It disappeared after one or two hours and it was more noticeable in the winter months when the windows were kept closed. We thought that this smell might have been due to the presence of phosgene but we were unable to detect any measurable concentrations of this substance. Five persons were subject to attacks of diurnal lassitude and two to feelings of substernal oppression.

Two case histories are recorded here in more detail because they are thought to be of interest, although their significance is doubtful.

Case 1.—A woman, aged 32, had been employed for 15 months and had been welding for 10 months. She stated that one day she suddenly developed difficulty in breathing, and wheezing. She was away from work for two weeks and was treated by her family doctor for bronchitis. She returned to welding but two days later she again began wheezing and continued to do so for four days, when she was transferred to other work and the symptoms subsided almost immediately. She had no further trouble but she has now left the firm. She had never suffered from a similar illness or any allergic disorder and the family history was not relevant.

Case 2.—A woman, aged 50, had been employed for 14 years and had operated a welding machine for eight months. Five months after she started welding she developed " a tightness of the chest " and wheezing. She remained at work with these symptoms for two weeks and then went off work for a fortnight and received treatment for bronchitis from her family doctor. This was her first attack of bronchitis. When she returned to work she continued welding but soon afterwards her symptoms recurred. She carried on for some weeks and the symptoms occurred spasmodically until eventually she remained at home for three days under the care of her family doctor. By this time the family doctor had decided that there was some relationship between her ill-health and her work and he advised alternative employment. Her work was changed and since then she has had only one week away from work, on account of laryngitis.

She stated that she had been subject to upper respiratory catarrh and to attacks of frontal sinusitis for many years and on one occasion she was operated on for nasal polypi. There was no family history of allergy.

During the investigation one male employee, aged 36, who was employed on an automatic welding machine in another workshop was interviewed. Because of the nature of his work he had to operate the machine with his face at about 8 to 10 in. from the arc. However, he was well screened from ultraviolet radiation. He complained of periodic attacks of nose and eye irritation, lacrimation, and " tightness of the chest ". He stated that these symptoms were more pronounced in the winter when the windows and doors were kept closed. No atmospheric sampling was carried out in the vicinity of this machine.

Two male employees from the degreasing shop were also interviewed; one, aged 48, had been engaged full-time on degreasing for seven years, but three months before the interview he was transferred to alternative employment because of his symptoms. He was complaining of lassitude at work, sleepiness in the evening, irritability, lack of concentration, and that his memory was defective. His wife came to see the nursing sister at the firm because she was worried that her husband had become bad-tempered and sleepy in the evening. The other, aged 44, replaced the above employee. He complained of lassitude during the day and of feeling sleepy in the evening and stated that he felt much more alert at the week-end. On one occasion when he was working overtime he became dazed and confused and had to be taken home for medical attention.

The symptoms described by these two employees were not unexpected in view of the concentrations

of trichloro-ethylene found in the atmospheric samples. Similar clinical effects from chronic exposure to this substance have often been reported in the past.

Discussion

Ozone.—The occurrence of ozone in nature, its properties and commercial preparation and its toxic properties are thoroughly reviewed by Stokinger (1954). The early symptoms in man are burning and smarting of the eyes and nose, headache, and lethargy; low concentrations may even put some people to sleep. Hill and Flack (1912) performed experiments on themselves and they reported that 2 to 3 p.p.m. of ozone quickly caused irritation of the upper respiratory passages; headache and a sense of oppression developed later.

Exposure to ozone is a hazard to those engaged in its preparation and use and to those working near high-voltage electrical equipment and ultra-violet lamps. It is a possible danger to high-altitude flyers. Wilska (1951) has described symptoms in technicians who used a spectrograph with an electric-spark source. The concentration of ozone was found to be 1 p.p.m. after the spectrograph had been in use for an hour. The technicians had irritation of the upper respiratory tract within 15 minutes, and after working under these conditions for a fortnight they were short of breath and had continuous headache.

Ozone is formed in small amounts in arc welding and in greater quantities in inert-gas shielded arc welding. Kleinfeld *et al.* (1957) described three cases of ozone intoxication in men using the latter process with consumable electrodes. They excluded poisoning by " nitrous fumes " and phosgene by air analysis at the breathing zone of the workmen, but the concentration of ozone was found to be as high as 9·2 p.p.m.

The present investigation shows that during inert-gas shielded arc welding of aluminium with non-consumable tungsten electrodes the important air contaminant is ozone (Table 1).

During the course of our investigation the maximum allowable concentration (M.A.C.) for ozone was reduced by the American Conference of Governmental Industrial Hygienists (1956) from 1 p.p.m. to 0·1 p.p.m. We were informed (Stokinger, 1956) that this reduction was recommended in view of reports of " nuisance symptoms " occurring at concentrations in the region of 1 p.p.m. Although the operators in our study did not complain of symptoms at exposures between 0·19 and 0·25 p.p.m. we are of the opinion that the decision to reduce the M.A.C. to its present value was a wise one.

Trichloro-ethylene.—Consideration of the concentrations of trichloro-ethylene in the atmosphere of the degreasing shop shows that at the operating position the concentration was near or above the M.A.C. under most of the conditions studied (Table 2). Above the tank, the concentrations were of the same order whether or not the tank covers were used. This suggests that the main source of air contamination arose from the degreasing vapour and liquid withdrawn from the tank when the work baskets were removed, rather than from the escape of vapour during the degreasing operation. The need for slow removal of the baskets from degreasing tanks is thus again emphasized. In addition, control of the direction of ventilation between welding and degreasing shops was considered necessary in view of the concentrations of vapour shown to exist at the doorway between the two shops.

Environmental Control

Ferry and Ginther (1952) considered that decomposition of trichloro-ethylene to phosgene, when it occurs, is probably due to radiation from the welding arc rather than to contact with the arc itself, and therefore, when welding is carried out in an open shop, radiation shielding is required in addition to local exhaust ventilation. The application of exhaust ventilation to inert-gas shielded welding must be carried out with caution, lest the gas shield itself be removed from the arc. In collaboration with the engineers at the factory, we carried out further experiments in order to determine an adequate rate of exhaust ventilation which would not affect the quality of the weld.

A test hood 7 in. by 12 in. was placed in position on the machine shown in Fig. 3, 2½ in. above the lip of the churn, and air was exhausted at the rate of 202 c.f.m., corresponding to a face velocity at the hood of 324 ft./min. This arrangement had previously been tested by the works engineers and shown not to affect the weld. Smoke tests, using titanium tetrachloride, and air sampling for ozone, with and without the exhaust hood in operation, suggested that complete control of gases and vapours was being attained.

A system of exhaust ventilation was subsequently installed on all the welding machines, and air sampling was again carried out at the positions shown in Fig. 4. The results of the analyses of these samples are shown in Table 3.

Smoke tests were also carried out at the same time on each machine to ascertain the effectiveness of control of the individual exhaust hoods (all of which were of necessity of different shape); in several instances modifications were found to be desirable and this work is now being undertaken. These improvements should result in further reductions

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2	B	0·23	
3	C	0·30	Ventilation required adjustment
4	D	0·19	General atmosphere
5	Outside factory	0	
6	A	0·25	
7	B	0·25	
8	Outside factory	0	

of the ozone concentrations. Since installation of the exhaust ventilation the only complaint has been from the operator of the machine at position C where the exhaust was subsequently found to be the least effective.

Adequate control of degreasing operations to prevent undue "drag-out" of vapour has been discussed in a previous paper (Hickish *et al.*, 1956). Since our investigation, exhaust ventilation has been installed in the degreasing shop with the dual purpose of reducing the exposure of the operator, and to ensure that the direction of air-flow is from the welding shop to the degreasing shop and not *vice versa*. Mechanical operation of the insertion and removal of parts from the tank has been installed, and the speed of removal controlled to 10 ft./min., thus minimizing "drag-out" of trichloro-ethylene vapour. The working conditions have therefore been greatly improved.

Summary

A description is given of the inert-gas arc welding process for aluminium, and of the formation of ozone during its use.

An environmental and clinical survey has been carried out in a workshop equipped with automatic inert-gas tungsten-arc welding machines. Ozone was found in the air in concentrations ranging from 0·8 to 1·7 p.p.m. Eleven out of 14 employees complained of upper respiratory symptoms.

No further symptoms were reported after ozone concentrations were reduced to the region of 0·2 p.p.m., and our findings thus support the decision of the American Conference of Governmental Industrial Hygienists (1956) to lower the M.A.C. for ozone from 1·0 to 0·1 p.p.m.

A system of local exhaust ventilation which did not remove the inert-gas shield and thus affect the quality of the weld is described, and the effectiveness of the system is demonstrated by substantial reductions in the concentrations of ozone in the workshop.

An account is included of an environmental and clinical investigation in a degreasing bay adjacent to the welding shop, and of the action taken to improve environmental conditions.

We are indebted to the management, employees, and nursing sister of the firm concerned for their willing and enthusiastic cooperation in this investigation, and to Professor G. P. Crowden for encouragement and advice.

Fig. 1 is published by permission of the Institute of Welding.

REFERENCES

Department of Scientific and Industrial Research (1939). *Methods for the Detection of Toxic Gases in Industry*, Leaflet No. 8. *Phosgene*. H.M.S.O., London.

Elkins, H. B. (1950). *The Chemistry of Industrial Toxicology*. Wiley, New York.

Ferry, J. J., and Ginther, G. B. (1952). *Amer. industr. Hyg. Ass. Quart.*, **13**, 196.

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Stokinger, H. E. (1954). *A.M.A. Arch. industr. Hyg.*, **9**, 366.

—— (1956). Personal communication.

Wilska, S. (1951). *Acta chem. scand.*, **5**, 1359.

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THE ESTIMATION OF GASEOUS ACID IN DOMESTIC PREMISES*

BY

J. J. PHAIR, R. J. SHEPHARD, G. C. R. CAREY, and M. L. THOMSON

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(RECEIVED FOR PUBLICATION SEPTEMBER 24, 1957)

While it is generally recognized that in most episodes of high atmospheric pollution it is difficult to incriminate any one circumstance, chemical or physical, as the responsible factor, there is also a measure of agreement that during such episodes the concentration of gaseous acids (particularly sulphur dioxide) reaches a higher level than normal; in combination with other adverse factors, such as a high relative humidity, an increased particulate loading, and a low external temperature, the change in gaseous acid concentration may be sufficient to cause disturbances of pulmonary function with serious consequences to patients having a small respiratory reserve.

Previous studies of sulphur dioxide concentrations (for instance Singh, 1939) have demonstrated quite wide variations between sampling stations in an industrial city; there may also be a significant gradient between the internal and external atmosphere of a building, particularly if the windows are closed (Setterstrom and Zimmerman, 1938; Wilson, 1954). A recent survey of the 1952 London fog episode (Ministry of Health, 1954) emphasized that during periods of intense pollution many of the disabled patients retired to their beds and remained there, and in the evaluation of the reactions of such patients to increased atmospheric contamination, it would therefore seem desirable to measure the concentration of gaseous acids and other variables within the micro-environment of the home.

The great variety of methods for estimating both SO_2 and SO_3 have been critically reviewed by Lombardo (1953). Many, while well suited to the analysis of stack gas, lack the sensitivity necessary to detect the concentrations normally present in the general atmosphere. The conductivity method, introduced originally by Saillard and Bregmann (1917) and now commonly attributed to Thomas and Abersold (1929), does possess the desired sensitivity, and under carefully controlled conditions an accuracy of 1% can be attained (Thomas, 1932). Further, the relative ease of the final analysis makes the conductivity method particularly attractive for field survey work such as our own, where approaching 200 separate analyses have to be made by a semi-skilled worker in the course of an afternoon. The main disadvantages of the Thomas autometer in such a study are its size and expense; it has also been found difficult to maintain the requisite constancy of temperature, liquid and gas flow under field conditions (Giever, 1952). An alternative to continuous analysis is some form of sequence sampler. The Wilson sequence sampler has proved reasonably satisfactory for outside sampling stations, but this apparatus is too bulky and too noisy for use in the home. Accordingly, to meet the objectives of our 1956 air hygiene survey (Carey, Phair, Shephard, Thomson, and Turner, to be published), it was decided to develop a small sequence sampler that would operate in the home for periods of up to three days with a minimum of servicing. This paper discusses some of the problems encountered in the construction of this apparatus and reports some observations on the relationship between domestic and community levels of gaseous acid contaminants of the atmosphere.

The Apparatus

Two models will be described. The first has seen successful use in the 1956 air hygiene survey in the City of Cincinnati (Carey *et al.*), while the second, now being developed, is even smaller and overcomes some of the technical problems inherent in the original design.

Model 1.—The apparatus is enclosed in a stained and varnished wooden cabinet measuring no more than 16 in. square and 14 in. high. Ventilation of the cabinet is obtained by a series of 1 in. circular ports on the front

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face of the cabinet and a small electric exhaust fan mounted over a larger port on the rear wall of the cabinet. To minimize conduction of sound, the cabinet is lined throughout by a ¾ in. layer of "C9 acousti-celotex" (Celotex Corp.).

A general view of the working parts is given in Fig. 1. The bubbler unit consists of 12 "opticlear" glass vials (Harshaw Scientific Company) standing in a removable hardboard rack. Each vial has a 15 ml. calibration mark engraved on the side and before use is filled to this level with a standard peroxide absorbent solution (9 ml. of 30% H_2O_2 and 0·93 ml. of normal H_2SO_4 in 19 litres of distilled water, adjusted to an initial specific resistance of approximately 50,000 ohms). The vials are closed with plastic stoppers, since it was found in initial experiments that several days' contact between the stock absorbent solution and a rubber bung was capable of producing a significant alteration in electrical conductivity. The plastic stopper is pierced by two tubes; one of 3 mm. internal diameter placed laterally is quite short, while the other, a central 1 mm. capillary tube, extends to within 2 to 3 mm. of the base of the vial (Fig. 2). The joints between glass and plastic are made gas tight by use of a plastic sealing compound ("glyptal", General Electric Company) applied under vacuum. The larger bore tube is connected by polyethylene tubing and a plastic quick-disconnect joint (Pioneer Plastics, Inc., Dayton, Ohio) to one of 12 solenoid valves mounted on an adjacent metal frame.

The solenoid valves (Asco valves, No. 82624) are each open for six hours in any one three-day cycle. They are controlled by an electrically driven cam (G.E.C. "telechron" three-day motor) bearing on 12 micro-switches (Fig. 2). The valves open in turn to a brass manifold of 1 in. internal diameter which leads to a quiet 1/70 h.p. diaphragm pump ("dyna" pump, Model 2, 115 volts). The initial output of the pump is 4 l./min., but it is reduced to approximately 1 l./min., by means of a

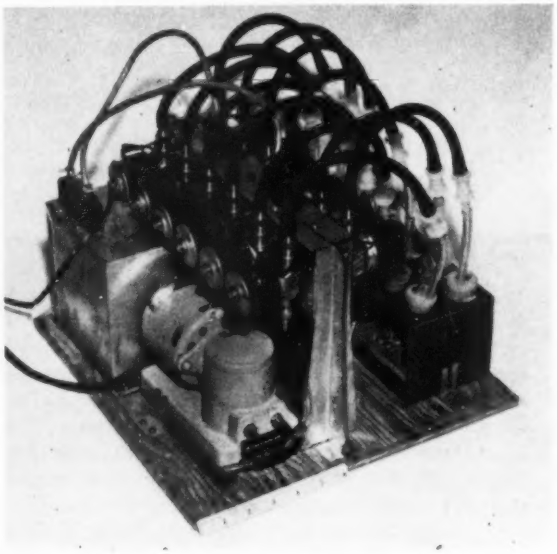


FIG. 1.—General view of sequence sampler (Model 1).

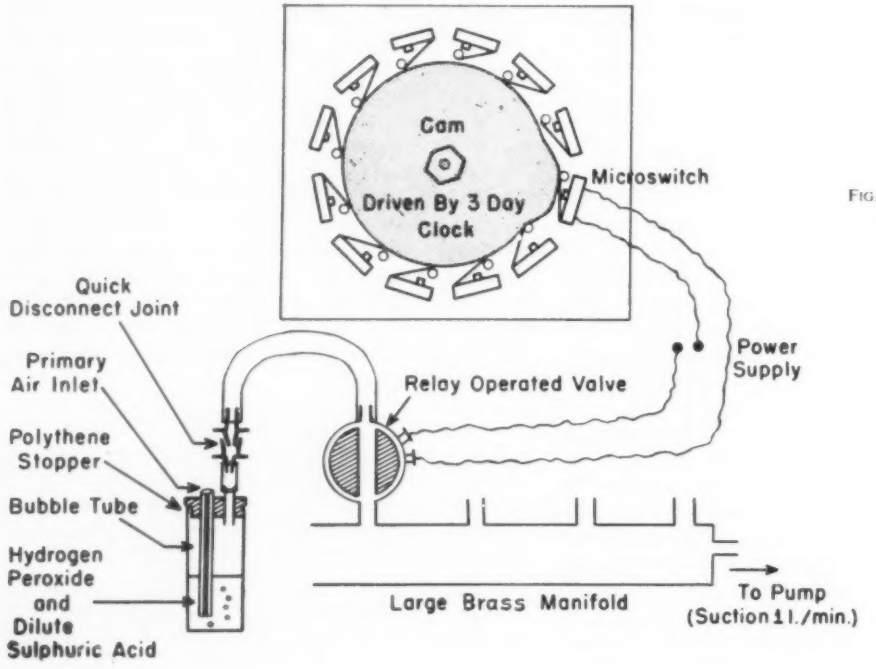


FIG. 2.—Schematic diagram of sequence sampler (Model 1).

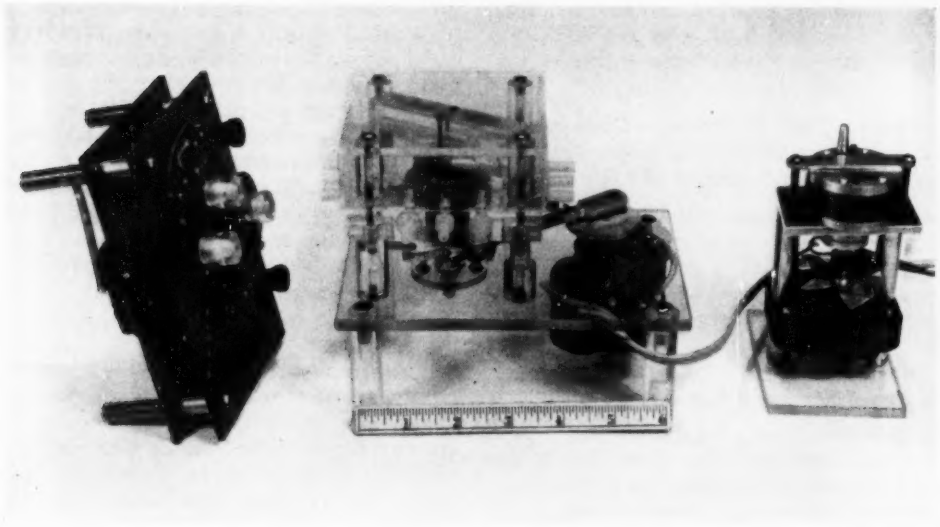


FIG. 3.—General view of modified sequence sampler (Model 2).

T-piece and appropriate capillary "bleeder". This bleeder tube is also essential to provide a by-pass flow of air through the pump during the change-over period when all the solenoid valves would be closed.

Model 2.—In this machine, heat production has been greatly reduced, since the 12 solenoid valves have been replaced by a plastic rotating head through which suction can be applied in sequence to each of the bubbler tubes. The head is moved quickly from one position to the next by a motor and cam mechanism. The timing unit consists of a clock and multiple plastic discs which can be interchanged to give individual sampling times ranging from two min. to six hr. or more. Bubbler tubes of the same type as used in Model 1 are arranged around the selector head. The overall dimensions of the entire unit, including bubbler tubes, are only 17 in. long, 11 in. wide, and 6 in. tall (Fig. 3).

Flow Characteristics of Sampling System

Some of the factors affecting sampling rate were investigated by operating a series of machines simultaneously for a period of several days. The majority of flow readings were made by rotameter, and it was found that the flow resistance was sufficient to reduce the pump output. In order to calculate the normal output of the pump, it was necessary to construct a pressure-volume curve for each pump and extrapolate to zero resistance (Fig. 4). Comparison of such extrapolated values with flow rates determined directly by low-resistance bellows flowmeter showed good agreement.

Differences in sampling rate attributable to machines, time of testing, bubbler tube (position in rack), and filling of vial ("full" or "low") were evaluated in a formal analysis of variance.

Effects due to Machines.—There is a highly significant component of the total variance attributable to differences between machines. This is largely attributable to varying amounts of dust accumulating in the capillary "bleeder", and will be discussed

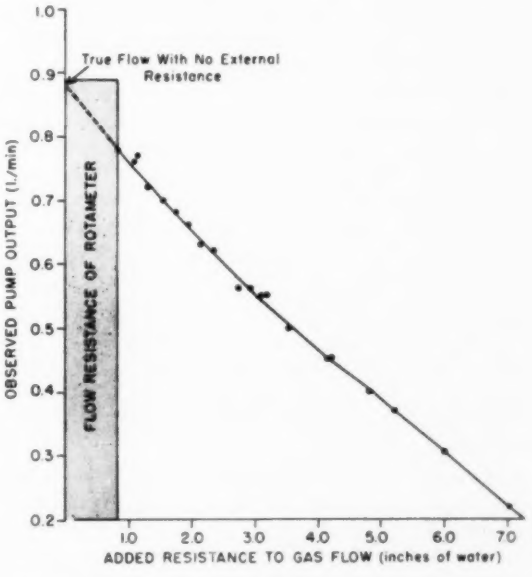


FIG. 4.—Pressure/flow diagram for diaphragm pump used in sequence sampler.

further in the section on field procedure. After cleaning the "bleeder" with chromic acid, the uniformity of flow in the different machines was restored.

Effects due to Time of Testing.—There are no significant systematic changes of flow when measurements are repeated over the course of a few minutes.

Effect of Position of Tube in Rack.—As might be expected, a small component of the total variance is attributable to the position of the tubes *per se*, and it is interesting to note also the magnitude of the first order machine/tube interaction. This implies that different bubbler tubes are behaving very differently in the same relative rack position. The critical factors determining flow through an individual vial are as follows:

Length of the Capillary Tube.—Over 90% of the total flow resistance of the sampling system from the atmosphere to the pump is attributable to the capillary tube. The rate of sampling shows an inverse relationship to the length of the capillary tube:

Length (cm.)	Flow (l./min.)
10	1·13
20	0·77
30	0·65
40	0·50
50	0·33

Variations in Internal Diameter of Capillary Tube.—Commercial capillary tubing has quite a wide nominal latitude with respect to bore, but direct testing of a number of 10 cm. lengths from one batch of 1 mm. tubing revealed variations of not more than 0·04 l./min. in sampling rate between different tubes.

External Shape of Capillary Tube.—It had been suggested that bubble formation might be facilitated by bevelling the ends of the capillary tubing, but direct measurement with a number of tubes before and after bevelling showed this to be unimportant.

Leakage at Plastic Stoppers.—With repeated use, it was found that some of the stoppers no longer made a perfect gas-tight seal with the glass of the vial. Tubes where leakage exceeded 10% of the total flow were rejected; since lesser leaks were fairly constant for any given stopper, it was possible to correct for them by determining the flow rate under a standard suction.

Effect of Depth of Filling of Vial.—There is no significant primary component of the flow variance attributable to the depth of filling of the vial, flow rates at the beginning of the sampling period (when the capillary tubes were immersed to a depth of 33 to 35 mm.) being identical with those at the end of the sampling period, when the tubes were immersed to a depth of only 1 to 2 mm. This is probably explained by the relatively small component of the total resistance attributable to passage of a gas bubble through the peroxide solutions. The tube position/filling interaction is highly significant, and is probably due to long-term variations in the power supply which affect all machines similarly over the four- to five-hour period between "full" and "low" flow measurements.

Summarizing this information, the standard error of the flow measurements is $\pm$ 0·065 l./min., and if three readings are taken over the space of about five minutes, 95% of observations made in this way will achieve an accuracy of $\pm$ 0·075 l./min. When the apparatus is used on domestic premises, it is important to minimize the component of variance attributable to "tubes", since only one of the 12 sampling positions can be checked by the visiting nurse. The technique of matching tubes according to flow rate will be described further in the section on field procedure.

Evaporation of Absorbent Solution

Perhaps the most serious problem with the original apparatus is that over the six-hour sampling period, the volume of peroxide solution is greatly reduced by evaporation, often to one-third of the original volume. Theoretical considerations suggest that at least four factors affect evaporation:

Water Vapour Content of Room Air.—At normal room temperatures (65-75°F.), fluctuations of relative humidity can produce appreciable changes in the water vapour content of the atmosphere. Expressing this in terms of partial pressure, extreme values of 3·3 and 12·6 mm. Hg were observed over a three-month period.

Volume of Air Drawn through Sampling Vials.—The importance of the flow rate in determining evaporation is evident from Table 1.

Temperature of Sampling Vials.—Enclosure of the entire apparatus within a sound-proof box creates a considerable heat dispersion problem. Some of the heat is generated by the pump and the telechron motor, but a more important source is probably the solenoids, since they are close to the sampling vials. The temperature of the peroxide solution is often as much as 30°F. above room temperature.

The importance of an increase of temperature in promoting evaporation is illustrated by a simple experiment in which an apparatus was removed from its cabinet. Initially, the temperature of the peroxide was little above that of the room, but as

TABLE 1

RELATIONSHIP BETWEEN EVAPORATION AND FLOW THROUGH SAMPLING UNIT

Machine No.	1	2	3	4	5	6	7	8
Average evaporation (ml.)	13·2	9·7	7·0	10·0	9·6	9·4	11·4	5·6
Average flow (l./min.)	1·65	1·20	0·84	1·12	1·02	1·41	1·24	1·13
Evaporation: flow ratio	8·0	8·1	8·3	8·9	9·4	6·7	9·2	4·9

TABLE 2

RELATIONSHIP BETWEEN TEMPERATURE OF SAMPLING TUBE AND AMOUNT OF EVAPORATION

Temperature of Sample (°F.)	Temperature of Room (°F.)	Relative Humidity (%)	Flow (l./min.)	Sampling Time (hr.)	Evaporation (ml.)
82	70	40	1·0	2	1·7
88	70	52	1·0	2	3·0
135	70	40	1·0	2	7·7

the apparatus was brought closer to a radiator, evaporation was markedly increased (Table 2).

It is difficult to obtain true average temperatures for the different cabinets, since the heat production varies from solenoid to solenoid, and even with any one solenoid from time to time. However, the lowest cabinet temperature observed was 14°F. above room temperature, and the highest 40°F. above room temperature.

Degree of Saturation with Water Vapour.—Theoretical considerations suggest that the air stream reaches 80-90% saturation at the temperature of the sampling solution. Consider a cabinet in a room at 70°F., and 33% relative humidity, the temperature inside the cabinet being 88°F. Room air contains water vapour equivalent to a partial pressure of 6·6 mm. Hg, while the vapour pressure with full saturation at 88°F. is 33·9 mm. Hg. The air will therefore require 27·3/760 litres of water vapour per litre to achieve full saturation. For one such cabinet, the total gas flow over a six-hour period was 409 litres, giving an uptake of 10·6 ml. of liquid for full saturation at 88°F. Direct measurement showed an average loss of 9·4 ml., indicating approximately 89% saturation.

An alternative approach is to operate a four-stage sampler at a comparable flow rate, and note the fluid loss in successive stages. Ten experiments of this type showed a total uptake for the four tubes that was invariably greater than the amount required to produce full saturation. This could not be explained in terms of spray being carried into the gas stream, and seemed due to a small amount of dry air leaking into the system around the stopper of each sampling vial. Assuming water loss at the fourth stage to be due entirely to this cause, it is possible to calculate corrected values for evaporation at the other three stages. At the first stage, the average value is 84·7%, agreeing well with the estimate made on theoretical grounds.

There are two possible methods of reducing evaporation. One is to increase the humidity of the air in the cabinet by feeding a continuous drip of water onto a suitable evaporating surface. This was rejected since a proportion of the gaseous acid might dissolve in the evaporating fluid, and oxidation of sulphur dioxide to the less readily absorbed sulphur trioxide would be promoted by the increased humidity. A more satisfactory approach is to decrease local heating by installing the solenoids, motor, and pump in an asbestos container ventilated independently of the rest of the cabinet. Modification of the sampling units along these lines has reduced evaporation from an average of 60% of the initial volume to 20 to 30%.

Calibration of Conductivity Apparatus

The specific resistance of the samples is measured by a standard conductivity bridge (Industrial Instruments, Inc., Cedar Grove, N.J.), the bubbler tubes being maintained at 80°F. by immersion in a constant-temperature bath. The apparatus was calibrated initially against sulphuric acid solutions of known normality prepared gravimetrically (Fig. 5). Over the range of interest in air-pollution work (specific resistance 10,000-50,000 ohms.), it is possible to read the bridge to the nearest 500 ohms. (rather more accurately at the lower resistance levels), giving an error of up to 5% in the estimate of sulphuric acid concentration. The readings are also quite sensitive to temperature, but once the bubbler tubes have warmed to the temperature of the water-bath, there is no further change of conductivity until the volume of solution is altered by evaporation.

Having determined the concentration of sulphuric acid in mg. per 15 ml. sample, it is necessary to convert the reading to parts per million of SO_2 in the atmosphere. At the temperature commonly found in the homes of our patients (25°C.), 1 mg. of liquid sulphuric acid is equivalent to 0·250 ml. of

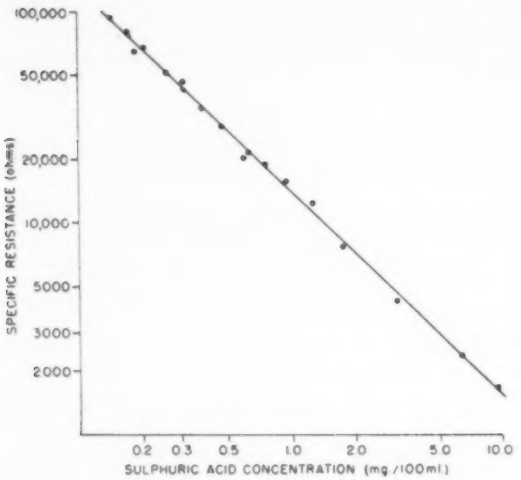


FIG. 5.—Calibration curve for conductivity bridge.

sulphuric acid or SO_2 in the vapour phase. Since the acid absorbed by the peroxide solution has been obtained from xt litres of room air (x being the bubbler flow in l./min., and t the total sampling time), an acid content of y mg. will be equivalent to 250y/xt p.p.m. of gaseous acid in the environment.

It will be noted that accurate timing of the solenoids is as important as the accurate measurement of conductivity in this calculation. This involves accurate positioning of the micro-switches in relation to the cam. The task could be made easier in future models by fixing the micro-switches in sliding grooves, or fitting switches with contacts of adjustable length. In practice, it is advisable to allow a short period in each six-hour cycle when all valves are closed in order to give the nurse adequate opportunity to change the bubbler tubes. This blank period must be timed accurately, and allowance made for it in the final calculations.

Efficiency of Single-stage Sampling

Theoretical considerations suggest that the efficiency of uptake of gaseous acid will be influenced by a variety of factors, including: (1) The shape and size of the gas bubbles; (2) the average contact time between gaseous and aqueous phases; (3) the temperature of the two phases.

Only the overall efficiency is of practical importance; this has been estimated by a four-stage sampling technique. The average value for 11 experiments was 95·3%, and in only two of the 11 experiments was the efficiency less than 90%. This compares well with more elaborate types of apparatus (Wilson, 1954; Lombardo, 1953). In two experiments where sampling was continued for 18 hours, evaporation was such that the capillary tube at the first stage was no longer in contact with the peroxide solution; in these experiments the efficiency dropped to 73 and 80% respectively.

In the early stages of this work, it was thought that the distance between the bubbler tube and the impingement plate would need to be rigidly controlled, and miniature plates of the Wilson (1954) type were made. However, direct comparison of such units with the simpler bubbler tubes in a fume chamber containing high concentrations of sulphur dioxide (2-20 p.p.m.) showed that there was no significant difference between the three systems, each showing a collecting efficiency of 93 to 95%.

Field Procedure

Where a considerable number of sampling units are operated simultaneously in different parts of a city, as during the recent air pollution survey, certain standard procedures become necessary. Each home is allocated two racks of numbered bubbler tubes, carefully matched for flow characteristics in order that the same factors may be used in subsequent calculations. The visiting nurse or technician reaches the home a little before the time of operation of the solenoid valve, and at the moment the valve closes, the quick disconnect joints are undone, and the new rack of bubbler tubes installed. The number of the last bubbler tube in the old rack and the first tube in the new rack are recorded on a suitable data sheet, and the old rack is brought back to the laboratory for measurement of electrical conductivity.

At this time, bubbler tubes are also checked for leakage by measuring the flow rate against standard suction. This is of some importance since, during a field visit, it is only possible to check flow through one of the 12 tubes.

Field checking of sampling rates is by means of a small rotameter (Brooks Rotameter Company) carefully calibrated in the laboratory. A small but progressive increase of gas flow rates was noted over the course of three months' operation. This was traced to a gradual accumulation of dirt in the capillary "bleeder". If it were desired to maintain an absolutely constant rate of sampling (as opposed to frequent rotameter checks), it would be necessary to have two matched "bleeder" tubes, and clean each weekly by immersion in chromic acid.

Significance of Measurements

It has been pointed out by Thomas, Ivie, and Fitt (1946) that the conductivity method is affected by gaseous contaminants other than the oxides of sulphur, notably hydrogen chloride and ammonia. The levels of these last two contaminants in the atmosphere of Cincinnati were investigated over a five-year period by Cholak, Schafer, and Hoffer (1952). Interpretation of the data is complicated by the fact that only "spot" samples were obtained and no samples were collected during wet weather, but

there is sufficient evidence to suggest that the concentrations of ammonia and chlorides are approximately equal, so that their effect on *p*H and hence on electrical conductivity should be slight. Neither amounts to more than 50% of the observed sulphur dioxide levels (measured as total sulphate).

Although some authors (Fox and Groves, 1932) have assumed that a simpler bubbler absorbs all of the "sulphur acids", critical investigation has shown that the amount of sulphur trioxide and sulphuric acid mist retained is slight unless very fine bubbles are produced by a sintered glass unit (Johnstone, 1931; Gillham, 1946) and the contact time is prolonged (Greenwood, 1939). However, the amount of sulphuric acid mist in the air of Cincinnati, even on a winter day, is small. Direct measurement of this contaminant was made by a modification of the method of Coste and Courtier (1936). Four sampling vials were arranged in series. The first two contained the standard peroxide absorbent, the third acted as a trap (it remained completely dry throughout the test), while the fourth was surrounded by ice to allow condensation of moisture, and the trapping of any aerosols. Over a period of 16 hours, some 15 ml. of condensate was obtained and measurement of electrical conductivity showed an acid content that was a little more than 3% of the value recorded for the peroxide solution. This agrees well with estimates made in other cities in the United States (Amdur, Schulz, and Drinker, 1952; Mader, Hamming, and Bellin, 1950). The fact that the sulphur trioxide level is so low implies that little would be gained by redesigning the bubbler unit to give complete absorption; variations in conductivity due to SO_3 would be submerged.

It must be concluded that except in areas where the level of atmospheric sulphur dioxide is unusually high, the measurement of "gaseous acid" is a relatively non-specific index of air pollution. However, as will appear in a following section, it is capable of yielding information that differs significantly from that given by other non-specific indices of pollution such as the determination of suspended particulate matter.

Variation between Sampling Units

In the Same Room.—It has already been noted that concentrations of gaseous acid can vary widely over comparatively short distances, and this immediately raises the question of the significance of measurements made at any one point in a room.

To investigate this problem, eight machines were distributed about a fairly large laboratory. In the first experiment, the SO_3 content of the air was artificially increased by placing several dishes of fuming sulphuric acid in front of an electric fan. An analysis of variance for three days' operation under these conditions showed that there was an almost one hundredfold gradient of gaseous acid across the breadth of the room. This was rather surprising, since a series of Hemeon smoke samplers, operating concurrently, showed a maximum difference of 25% in the suspended particulate matter at different points in the room. A possible explanation is that in the immediate vicinity of the evaporating dishes the SO_3 is in gaseous form, which is readily absorbed in the sampling vials, but as the fume crosses the room it is rapidly hydrated to sulphuric acid aerosol which is not absorbed.

Repetition of the experiment without the forced draught of SO_3 gave values that were reasonably similar at different points in the room. The total observational variance was such that any six-hour measurement made with one machine at one point in a room had 95% confidence limits of $\pm 28 \times 10^{-4}$ p.p.m. SO_2. This is at least adequate for estimating the mean daily gaseous acid levels in a room, and compares quite well with values for the Wilson sequence sampler operated under similar conditions (95% confidence limits for one-hour sample $\pm 45 \times 10^{-4}$ p.p.m. SO_2).

Readings Inside and Outside of a Building.—The penetration of gaseous acid into a closed room was followed for a two-month period. Two-hourly Wilson sequence samplers were operated inside and outside a room in the Cincinnati General Hospital. The room was the size of a typical bedroom, and the windows and door were closed except when the samples were being changed. Linear regression methods were utilized in measuring the extent of the relationship between inside and outside measurements. Table 3 shows the percentage of the variation of inside measurements attributable to variations in external gaseous acid for different lag periods. It will be noted that there is a maximum correspondence with a lag of somewhere between zero and two hours, the exact value being perhaps somewhat closer to two hours. The inside values did not show the same sharp peaks as the outside values, and the

TABLE 3

PERCENTAGE VARIATION COMMON TO INTERNAL AND EXTERNAL LEVELS OF GASEOUS ACID FOR VARIOUS DISCREPANCIES IN TIME OF SAMPLING

Lag Period (Hours) (time inside to time outside)	Percentage Variation Common to Inside and Outside Measurements
−2	17
0	41
2	41
4	26
6	11
8	7

TABLE 4

PROPORTION OF GASEOUS ACID PENETRATING CLOSED ROOM AT DIFFERING EXTERNAL CONCENTRATIONS

External Concentration (p.p.m.)	Internal Concentration (p.p.m.)	Inside/Outside (%)
0·08	0·060	75
0·16	0·095	59
0·24	0·120	50
0·32	0·140	44
0·40	0·160	40
0·48	0·175	36

mean indoor value was no more than 64% of the outside value over the entire two-month period. It is also interesting to note (Table 4) that with increasing external concentrations of gaseous acid, the proportion penetrating the building materially decreased. This may be because many of the peaks of contamination were of comparatively short duration.

As a consequence of the average lag of almost two hours, it follows that when the outside concentration is falling rapidly, the inside value may exceed the outside value for a time and this has actually been observed on a number of occasions. The smaller variation of gaseous acid in the home is of some practical importance in that it suggests that reliable information can be obtained with a lower frequency of sampling than is necessary out of doors.

Variation between Different Outdoor Stations.—Hourly samples were obtained from each of three outdoor stations in different parts of the town over the course of a three-month period. Highest values were consistently recorded from a downtown area (city parking lot); taking this as unity, values at the two suburban locations (medical school two miles north of the city centre and Abbé Observatory four miles north of city centre) showed a slight decrease as winter developed. Relative monthly levels of gaseous acid, taking the city parking lot as unity, were as follows:

	October	November	December
City parking lot	1·00	1·00	1·00
Abbé Observatory	0·56	0·45	0·43

This change is probably related to the greater density of housing units in the downtown area. Thus, a higher proportion of the downtown gaseous acid is attributable to the domestic heating load and there is a correspondingly greater seasonal variation in contaminants from this source. Since the relationship between outdoor stations is by no means constant, it is necessary to operate a fair number of sampling units simultaneously to obtain an overall picture of the pollution of a city at any given time.

Relations to Other Indices of Atmospheric Pollution

A number of authors have noted a relationship between gaseous acid levels and the concentration of suspended particulate matter, and it may be asked whether any advantage is derived from measuring both quantities. However, simple graphical examination of the data (Fig. 6) is sufficient to show that the relationship between the two indices of pollution varies considerably from one part of the city to another. In the downtown area (city parking lot) (Fig. 6*a*) the gaseous acid follows the pattern of particulate concentrations fairly closely, although there is apparently a lag of two to three hours between the two curves. The ratio of the two measurements is also fairly constant under conditions of high and low pollution averaging 40 to 60 COH* units per p.p.m. At the Abbé Observatory (Fig. 6*b*), situated on a high bluff overlooking an industrial valley, there is little or no lag between the two curves, but the gaseous acid levels are not sustained for as long as the smoke readings. It may be that there is more free ammonia in this area giving rapid neutralization of the gaseous acid; this would also explain why under conditions of low pollution the particulate levels bear a very high ratio to gaseous acid concentrations (2 to 300 COH units per p.p.m.). The third station (medical school) occupies a geographic position intermediate between that of the Abbé Observatory and the city parking lot. Here, the gaseous acid curve lags behind the particulate curve by 0 to 1 hour, and the acid level is maintained for a similar period to the particulate matter.

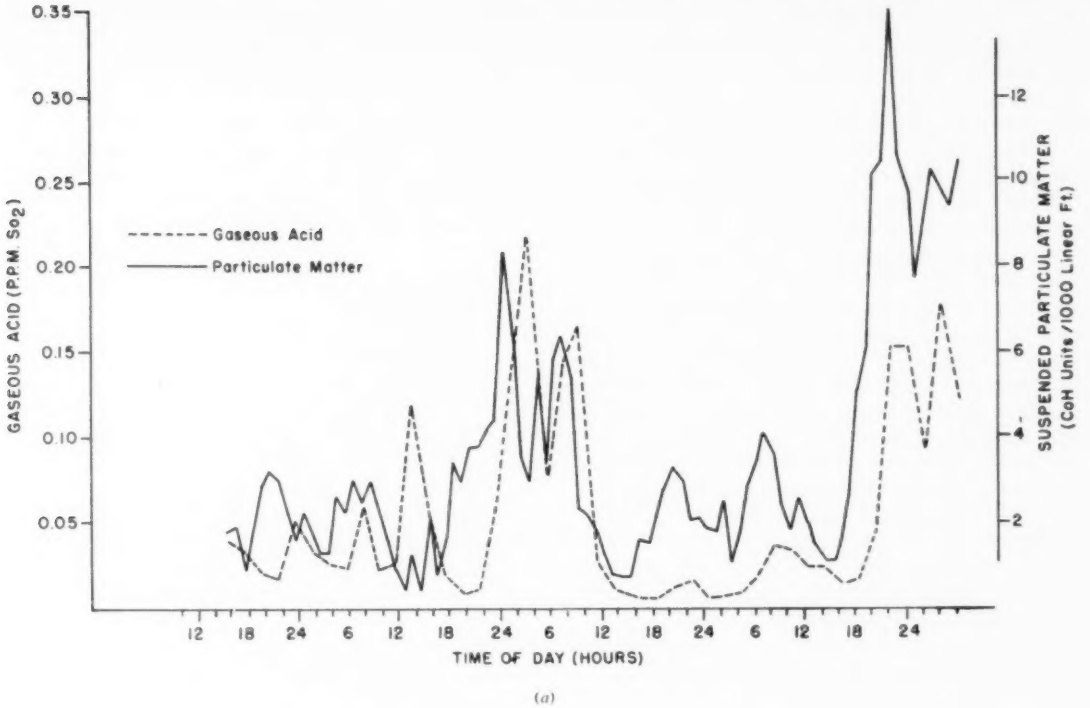
RATIO OF PARTICULATE MATTER TO GASEOUS ACID AT THREE LOCATIONS

	Abbé Observatory	Medical School	City Parking Lot
Light pollution	213	369	77
Heavy pollution	69	82	47

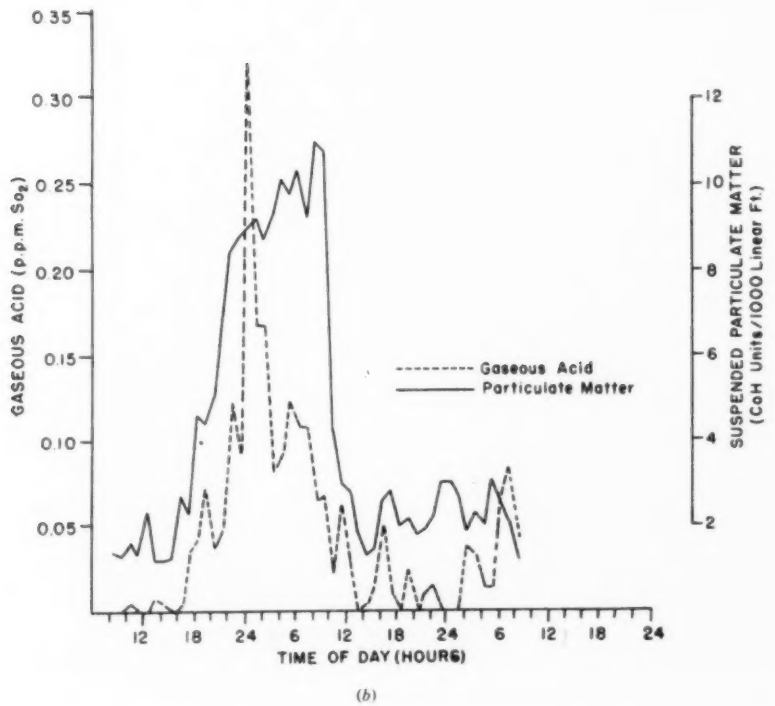
Other Possible Applications

Although designed primarily for use in a domestic air hygiene survey, the compact portable nature of this apparatus suggests that it may find ready application in many industrial situations where accurate sequential measurements of gaseous contaminants are desired. The low cost and simplicity of operation also make the apparatus very suitable for large-scale grid measurements of gaseous acids in a large city.

*A COH unit may be defined as that quantity of suspended particulate matter which, when deposited on a filter strip, produces on optical density of 0·01.



(*a*)



(*b*)

FIG. 6.—Relationship between gaseous acid and suspended particulate matter.
(*a*) At downtown location
(*b*) At the Abbé Observatory

Summary

A description is given of a small sequence sampler that gives six-hourly readings of gaseous acid concentration in domestic premises. Samples are returned to the laboratory for analysis by the conductivity method. Factors affecting the rate of sampling and evaporation of absorbent solution are critically evaluated. Evaporation is an important problem with the original model and methods of minimizing water loss have been incorporated in later designs of the apparatus. Gaseous acid measurements largely reflect the amount of SO_2 in a suburban atmosphere and an efficiency of 95% can be obtained with single-stage sampling. Ammonia and hydrochloric acid vapour are also absorbed although these are present in lesser and approximately equal amounts. Sulphur trioxide is not absorbed to any significant extent, but this is a minor constituent of suburban atmospheres.

The variation between different sampling units in the same room is considerable in the presence of dry gaseous SO_3, and even under normal room conditions the 95% confidence limits of observations made from a single point are $\pm$ 0·0024 p.p.m. Differences between different parts of a large building are even greater. Indoor measurements show a general tendency to follow outdoor readings with a lag of up to two hours; however, the indoor concentrations of gaseous acid are on the average much lower, and do not show the sharp peaks seen at outside locations. The relationship between gaseous acid levels in different parts of the city is not constant since in each area the industrial output is supplemented by a seasonally varying domestic heating load. The relationship between gaseous acid and particulate contaminants also varies in different parts of the town, perhaps on account of differing amounts of alkaline pollutants in the atmosphere.

References

Amdur, M. O., Schulz, R.Z., and Drinker, P. (1952). *A.M.A. Arch. industr. Hyg.*, **5**, 318.
Carey, G. C. R., Phair, J. J., Shephard, R. J., Thomson, M. L., and Turner, M. E. *The 1956 Air Hygiene Survey in the City of Cincinnati.* In preparation.
Cholak, J., Schafer, L. J., and Hoffer, R. H. (1952). *A.M.A. Arch. industr. Hyg.*, **6**, 314.
Coste, J. H., and Courtier, G. B. (1936). *Trans. Farad. Soc.*, **32**, 1198.
Fox, J. J., and Groves, L.G. (1932). *J. Soc. chem. Ind. (Lond.)*, **51**, 7T.
Giever, P. M. (1952). *A.M.A. Arch. industr. Hyg.*, **6**, 445.
Gillham, E. W. F. (1946). *J. Soc. chem. Ind. (Lond.)*, **65**, 370.
Greenwood, H. D. (1939). *Industr. Chemist*, **15**, 113.
Johnstone, H. F. (1931). *Industr. Engng Chem.* **23**, 620.
Lombardo, J. B. (1953). *Analyt. Chem.*, **25**, 154.
Mader, P. P., Hamming, W. J., and Bellin, A. (1950). Ibid., **22**, 1181.
Ministry of Health (1954). Reports on Public Health and Medical Subjects. No. 95: *Mortality and Morbidity during the London Fog of December*, 1952. H.M. Stationery Office, London.
Saillard, E., and Bregmann (1917). *Rev. gén. Chim.*, **20**, 69.
Setterstrom, C., and Zimmermann, P. W. (1938). *Contrib. Boyce Thompson Inst.*, **9**, 171.
Singh, A. D. (1939). A Survey of Sulphur Dioxide Pollution in Chicago and Vicinity. University of Illinois. Engineering Experiment Station. Circular No. 36.
Thomas, M. D. (1932). *Industr. Engng Chem. (Anal. Ed.)*, **4**, 253.
——, and Abersold, J. H. (1929). Ibid., **1**, 14.
——, Ivie, J. O., and Fitt, T. C. (1946). Ibid., **18**, 383.
Wilson, W. L. (1954). *An Automatic Impinger for Air Sampling.* Annual Meeting, Air Pollution Control Association. Chattanooga, Tennessee, May 3-6, 1954.

Brit. J. industr. Med., 1958, **15**, 293.

QUARRY BANK MILL

1. THE STORY OF THE MILL

BY

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Quarry Bank Mill, elegant and ivy covered, stands in the peaceful valley of the river Bollin, not 10 miles south of the centre of Manchester. Its fine Georgian façade, set off by great banks of trees, and surrounded in their seasons by daffodils, bluebells, and flowering shrubs, offers a striking contrast to the gaunt lines and forbidding aspect of its more modern counterparts not far to the north.

Through the generosity of its former owners, the Greg family, the mill and its surroundings, including the picturesque village of Styal, are now the property of the National Trust, ensuring that this most beautiful of all cotton mills will be preserved to posterity as an example that industry need not of necessity be cradled in ugliness.

But its interest for us lies not in its beauty, nor in its undoubted commercial success, but in the fact that here, before any legislation was enacted, there existed a health and welfare service, generous in its provisions and in its application. By good fortune the records of the medical officers, covering the years from 1804 to 1847, have been preserved

FIG. 1.—Quarry Bank mill. Samuel Greg's house can be seen at the end of the façade beyond the mill chimney.

at the mill, a unique testament to this pioneer occupational health service which will be described in the second part of this essay.

Samuel Greg (1756-1834)

The mill was built in 1784 by Samuel Greg, the son of Thomas Greg, a Belfast shipowner, and Elizabeth Hyde, the sister of Nathaniel and Robert Hyde, fustian manufacturers, of Manchester. The boy was educated first at Harrow, and then at a rival school at Stanmore. Upon leaving school he went to work for his uncles, who seem to have been impressed by his ability and industry, for in due course they offered him the inheritance of their business.

This was a time of great activity in the cotton industry. Arkwright had recently patented the water frame (1769) and Hargreaves, though more deserving, had been denied the patent rights for his spinning jenny (1770). The new mass-production industry of cotton spinning was getting under way and Samuel Greg, not slow to realize its possibilities, resolved to build a spinning mill, taking as his partner John Massey, who unfortunately died within a year. Together with Hugh Oldham, a surveyor, they prospected along the banks of the river Bollin in search of a suitable site, and at a spot then called Ferney Brow, they calculated (and the figures can still be seen at the mill) that the fall of water was just enough to operate a water-wheel at the necessary horse-power. The name Ferney Brow, however, suggesting as it did the philosopher of Ferney (Voltaire, 1694-1778), did not commend itself to a New Light Presbyterian, and the name Quarry Bank was therefore adopted from a farm close by which was bought four years later. In the deeds which are preserved in the Rylands Library, Manchester, Samuel Greg promised " the preservation of the sylvan amenities ", and the beauty of the locality at the present time shows that he was a man of his word.

In 1787 he married Hannah Lightbody and built a pleasant house at the northern end of the mill, at the same time retaining his town house in King Street, Manchester. There they raised a family of sons and daughters, all of whom shared the obligations of a philanthropic employer and the advantages of a rapidly developing business. There, too, Samuel Greg died in 1834, following injuries received when he was charged by a deer in the carriageway in front of the house.

The first lease of the land was taken out in January, 1784, and by early summer the mill, a four-storey building, ninety feet long by thirty feet wide, with mullioned windows and a little bell tower, was in operation. The total cost, including Arkwright machinery, was £16,000. The first employee was a local girl called Peggy Chapman, who started work in May, 1784. Soon there were 150 men, women, and children employed—the last in the majority—operating the 3,000 spindles worked by two wooden water wheels ten feet in diameter. The men earned 10s. to 12s. a week, the women 5s., and the children 1s. 6d. to 3s. The Brazilian cotton used was bought at 5s. a pound, and after being spun into warp for the finest muslins, was sold at 20s. a pound. Some work was put out to other factories nearby and to domestic spinners and handloom weavers.

After 11 years Peter Ewart, a Scottish engineer trained at the factory of Boulton and Watt in Birmingham, was taken into partnership. New machinery was installed, the original machines being of poor design with much wood in their construction, and a fresh weir was built to give a greater head of water. (This weir still exists and on its western side can be seen a small cave in the rocks, originally called Disley Kirk after a hermit who lived there.) The mill was enlarged southwards to double its length, an attic storey was added, and the original wooden wheels were replaced by an iron wheel, the first in the country. This was a breast wheel with buckets or troughs instead of blades or paddles, 32 feet in diameter and 21 feet wide, weighing 43 tons and producing 100 nominal horse-power.

The mill was said to impound more than its fair share of the water power available and legal difficulties arose with the owner of a corn mill at Ashley, a few miles down the river, who was deprived of water, and with the tenant of Pownall Hall, whose land was occasionally flooded. These troubles and the demand for more water power resulted in the installation in 1800 of a 10 h.p. engine by Messrs. Boulton and Watt, the receipt for which can still be seen at the mill (Quarry Bank MSS.).

Transport

Before the mill was built the only form of transport in existence in the area was the pack horse. But soon roads began to replace the bridle paths and " lumbering carts with wide fellies " carried the finished yarn via Oversley Ford to Altrincham where there was a quay on the Bridgewater Canal at Broadheath. In the beginning two farmers arranged the cartage, but later Samuel Greg bought his own wagons. This system of transport remained in use for 90 years (Henshall, 1957).

Labour Supply

The total population of Styal in 1787 was 420, and until the coming of the mill the community had

existed mainly on domestic industries, though there was a small tannery and bootmaking establishment. Mohair and silk stitched and lapped buttons were made from material brought by the " putters-out " from Macclesfield, and jersey, a cotton and wool mixture was spun on what were called "tow" wheels. The jersey material was brought from Yorkshire by the salters who used the caves near Quarry Bank as a camp on their way with pack horses to Middlewich and Northwich. Such was the industry of the people that " boys and girls of 6 years old could almost earn their living " (Finney, 1785). At 8 years they could earn 3d. to 4d. a day, and an active, diligent woman, 4s. a week. The fashion for mohair buttons was short-lived, and the supply of the raw material for jersey spinning was uncertain, but they produced in the village a reservoir of skilled and semi-skilled labour which welcomed the opportunity of regular employment afforded by Quarry Bank Mill.

The population of 420 in 1787 consisted of 131 householders, 149 male children, 114 female children, 14 male servants, and 12 female servants. This had increased to 523 by 1801, of whom 114 were engaged in agriculture, 227 in trades, and 132 in neither. (The remaining 50 were probably children under working age.) The numbers employed at the mill were, according to the wage books, in 1790, 263, in 1820, 448, in 1848, 421, and in 1851, 413. The average distribution of employees was 27% men, 39% women, 19% boys, and 15% girls. Some of the additional labour came from Wilmslow and outlying villages and male labour was imported from as far as Nantwich and Manchester. The social restlessness of the times led to an influx of labour from many other districts, much of it casual and unreliable. Though in some cases whole families might be sent by the Poor Law authorities, the characteristic of the times was the employment of young children from the poorhouses —the parish apprentices.

Apprentices

Much has been written about the employment of parish apprentices, rescued in their infancy by a philanthropy which only saved their lives for an unhappier fate in their youth. The Boards of Guardians, saddled with a rising population in the workhouses and no doubt as anxious to equip the young people with a trade as to get them off their hands, thankfully shifted the responsibility for their maintenance to the employers clamouring for cheap labour. The stories of Robert Blincoe (Brown, 1832) and Michael Armstrong (Trollope, 1840) describe the conditions under which some of these " little slaves " had to work. Samuel Greg, in employing them, followed what was only common practice at the time but, under the benevolent care of his family, these children were much better off than they would have been under " the step-motherly care of the Poor Law ". Lazenby (1940) says that local children were not employed to the same extent because factories were linked in the minds of the people with workhouses and so Samuel Greg had to go to the workhouses for his hands.

In 1785 pauper apprentices were obtained from Newcastle-under-Lyme and the indenture of the first of these is still preserved.

> It " witnesseth that Thomas Payne churchwarden of the Parish and Borough of Newcastle in the County of Stafford and Thomas Barratt Overseer of the Poor of the said Parish and Borough by and with the consent of His Majesty's Justices of the Peace for the said Borough do put and place Thomas Royley a poor child of the said parish (eleven years old) apprentice to Samuel Greg Esq of Manchester Cotton Manufacturer with him to dwell and serve from the day of the date of these presents until the said Apprentice shall accomplish his full age of twentyone years. . . . During all which time the said Apprentice his Master faithfully shall serve in all lawful businesses according to his Wit Power and Ability and honestly orderly and obediently in all things demean and behave himself towards this said master. . . and the said Samuel Greg shall and will during all the term aforesaid find provide and allow unto the said Apprentice meet, competent, and sufficient Meat, Drink, Apparel, Lodging and Washing and other things necessary and fit for an apprentice."

Later on they came from contiguous parishes in the south and even from as far as Norfolk and Somerset, though an Act of 1816 limited the area from which apprentices could be engaged. After 1830 the bulk of the apprentices were Irish immigrants from Liverpool. None was accepted at the mill under the age of 9. Many of them continued to work at the mill at the end of their apprenticeship and until late in the nineteenth century many villagers of Styal spoke with a " foreign ", *i.e.*, southern, accent.

About the year 1790 an apprentice house, which still stands, was built at a short distance from the mill. It was capable of housing 100 apprentices between the ages of 9 and 21. Dr. Andrew Ure (1835) described the mill and its amenities as follows:

> " At Quarry Bank, near Wilmslow, in Cheshire, is situated the oldest of the five establishments belonging to the great firm of Messrs. Greg and Sons, of Manchester, who work up the one-hundredth part of all the cotton consumed in Great Britain. It is driven by an elegant water-wheel, thirty-two feet in diameter, and twenty-four feet broad, equivalent in power to one hundred and twenty horses. The country round is beautiful and presents a succession of picturesque wooded dells, interspersed with richly cultivated fields.

FIG. 2.—The Apprentice House at the present time.

At a little distance from the factory, on a sunny slope, stands a handsome house, two stories high, built for the accommodation of the female apprentices. Here are well fed, clothed, educated, and lodged, under kind superintendence, sixty young girls, who by their deportment at the mill, as well as in Wilmslow church on Sunday, where I saw them assembled, evince a degree of comfort most creditable to the humane and intelligent proprietors. The Sunday scholars, equally numerous, belonging to the rural population, appeared to great disadvantage alongside of the factory children, the former being worse clad and worse looking than the latter, and worse behaved during divine service.

Messrs. Greg spin about 60,000 lbs. of cotton per week in their five mills, which amount to the prodigious quantity of 3,120,000 lbs. per annum, being the largest concern in the kingdom. One farthing per pound on the price of cotton wool makes a difference to them of £3,000 a year.

The female apprentices at the Quarry Bank Mill come partly from its own parish, partly from Chelsea but chiefly from the Liverpool poor-house. The proprietors have engaged a man and a woman, who take care of them in every way: also a schoolmaster and a schoolmistress and a medical practitioner. The Messrs. Greg are in the habit of looking after the education of the boys and their sisters superintend that of the girls, who are taught reading, writing, arithmetic, sewing and other domestic avocations. The health of these apprentices is unequalled by any other class of work-people in any occupation. The medical certificates laid before the Factory Commissioners prove that the deaths are only one in one hundred and fifty, being no more than one-third of the average of Lancashire. Their ages vary from ten to twenty-one years. When they grow up, they almost always marry some of the men belonging to the factory, often continue to work, and receive better wages than the other operatives, as they are obliged to take houses for themselves. Only one or two instances have occurred in the course of forty years, since the system was begun by Mr. Greg, senior, of any of them coming on the parish. The apprentices have milk-porridge for breakfast, potatoes and bacon for dinner, and butcher-meat on Sundays. They have bacon every day. About five hundred and fifty young people of this description have passed through that mill in the course of forty years. Mr. W. R. Greg says that the general state of education among their mill hands is remarkably superior to that of the agricultural people. He has attended sometimes a sort of little club established near one of their country mills, to which some of the farmers' people came, and he found an astonishing difference between their intelligence and that of the mill workers. He has observed that the children are a great deal more fatigued and less willing to go to school after a holiday, than after the business of an ordinary day. They all attend school with regularity."

While the opinions of Ure cannot always be taken literally, the stock books, containing notes of the food bought and used at the apprentice house and still preserved at the mill, support his view in this instance. As further evidence there is the statement of two boys, Joseph Fulton (17) and Thomas Priestly (13), who were brought before the Middlesex Magistrates in 1806 charged with having " eloped and deserted the service of Samuel Greg, cotton manufacturer, of Pownall Fee in the County of Chester, to whom they were apprenticed ".

They walked the whole of the way to London to see their families and were arrested four weeks later. To the magistrates they gave a full and particular account of their work, manner of treatment, diet, and clothing. After describing the nature of their

employment and their satisfaction at the treatment they received from all in charge of them, they go on to say:

> " . . . there were 42 boys and more girls apprentices; we lodged in the ' Prentice House ' near the mill and were under the care of Richard Sims and his wife. The boys slept at one side of the house and the girls at the other. The rooms were very clean, the floors frequently washed and aired every day; also whitewashed once a year. Our beds were good. We slept two in a bed and had clean sheets once a month. We had clean shirts every Sunday and new clothes for Sunday once in two years; also new working jackets when those in use were worn out."

Their diet consisted of beef (occasionally on Sundays), boiled pork, bacon, potatoes, peas, beans, and other vegetables in their season, bread, milk, milk-porridge, thick porridge, and tea when ill.

> " On Sunday we went to Church in the morning and to school in the afternoon, after which we had time to play. We also had a school every night which we used to attend once a week beside Sundays, eight boys going at a time." (Quarry Bank MSS.)

Another writer describing their appearance says: " The plain light straw bonnets of the girls were bound over the head with a green ribbon. The neat drab dresses were of a stout (green) cotton material, a sort of thinnish fustian, and the bust was concealed by a cross-over buff handkerchief. Woollen stockings and substantial shoes protected their feet and cloaks shielded them from wet or cold. The lads wore dark (green) corded breeches (with red collars and cuffs), woollen stockings and stout shoes. Their jackets were of strong fustian and they wore high-crowned hats " (Fryer, 1886).

Their working hours, 5.30 a.m. to 8 p.m., were long even by the standards of those days. There was a break of 10 minutes at 8.30 for breakfast and half-an-hour at 1 p.m. for dinner. A meal was provided at 5.30 p.m., while the machines remained in motion. When trouble arose over the water supply, overtime might be worked. The time register required under the first Factories Act of 1833 can still be seen at the mill and gives ample evidence of the frequency of this type of interruption and consequent overtime.

Discipline

Discipline was strict. Corporal punishment was administered in some cases and fines in others for bad conduct and for damage to property. Fines were severe, " breaking a lamp glass 4s.", " breaking a window-pane 1s. 4d.", " breaking a window-pane at the Master's house 8s.", " stealing apples 5s.", " for standing on the lodge steps and going out 5s". Twenty-three children absconded between 1815 and 1845, of whom only four evaded capture. Good work, on the other hand, brought its reward, for a sixpence might be found on an apprentice's machine after the manager or the master had passed that way.

Education

The object of the education provided, *viz.*, " to enable the workers to act on instructions ", was perhaps not wholly disinterested ! In 1798 regular visits by a teacher were instituted on Sunday afternoons, and there was also a singing class under a special teacher. An examination, conducted by the Greg family, was held each Christmas. The use of the slide rule was taught and it is of note that James Henshall, manager from 1847 to 1867, made some important contributions to its design.

In 1823 Samuel Greg built a small school for the children of the village to which the apprentices went in relays for two hours a day. In the same year an adult " mutual improvement society " was started, to which the sons of the family gave lectures during their university vacations. This was still in existence in 1863 but by then it had achieved the status of a " Mechanics Institute ".

Other Activities

In addition to the village school, Samuel Greg, who had difficulties over the payment of tithes to the parish of St. Bartholomew in Wilmslow, built a Unitarian chapel in 1822. He provided homes in the village for his employees, some adapted from farm buildings and some newly constructed from locally-made bricks. Many of these cottages are still standing and add to the charm of the village. A shop was also provided at which employees could make purchases, the cost being deducted from their wages, a system which had to be abandoned in 1831 with the first Truck Act, though there was no evidence of excess profits, in fact, the reverse. A profit-sharing system was begun in 1850 and abandoned in 1863. In 1873 it became the Styal Co-operative, later absorbed into the Stockport Co-operative Society.

Epilogue

A Scotsman, hearing in the story of this pioneer mill-owner an echo of his country's history, may perhaps be forgiven for mentioning one final item of interest in the story of Quarry Bank. For Samuel Greg was the great-great-grandson of William Greg of Ochiltree in Ayrshire, one of the MacGregors who, like Rob Roy, was obliged to adopt another name when the clan was proscribed during the seventeenth century. In the survival of Quarry Bank throughout the chequered history of the cotton industry, and in the knowledge that it will be preserved in the perfection of its rural setting as a part of our national

heritage, there is surely a reminder of the words of Sir Walter Scott's defiant song:

" While there's leaf in the forest and foam on the river, MacGregor, despite them, shall flourish for ever."

I should like to express my warmest appreciation of the patience, kindness, tolerance, and historical knowledge of Mr. Samuel Henshall, the present manager of the mill, who represents the fourth generation of Henshalls to have worked there. I am indebted also to Dr. A. L. Finney for making available to me the manuscript of the history of Wilmslow written by his ancestor, Samuel Finney, Lord of the Manor of Fulshaw.

(To be concluded)

References

Brown, J. (1832). *A Memoir of Robert Blincoe*: An orphan boy; sent from the workhouse of St. Pancras, London, at seven years of age, to endure the horrors of a cotton-mill, through his infancy and youth, with a minute detail of his sufferings, being the first memoir of the kind published: by John Brown. Printed for and published by J. Doherty, 37 Withy Grove, Manchester, 1832.

Finney, S. (1785). *An Historical Survey of the Parish of Wilmslow*. In manuscript. By courtesy of Dr. A. E. Finney, Wilmslow.

Fryer, (1886). *Wilmslow Graves*. *Stockport Advertiser*. Printed for the author.

Henshall, S. H. (1957). Personal communication.

Lazenby, W. C. (1940?). *The Social and Economic History of Styal*. Thesis in Christie Library, Manchester University.

Quarry Bank MSS. An extensive collection of diaries and other documents is kept at the mill.

Trollope, Frances (1840). *Life and Adventures of Michael Armstrong, the Factory Boy*. Henry Colburn, London.

Ure, Andrew (1835). *The Philosophy of British Manufactures*, as reviewed in Chambers' Edinburgh Journal No. 185, August 15, 1835, **4**, 229.

BOOK REVIEWS

Industrial Deafness. Hearing Testing and Noise Measurement. By Joseph Sataloff. (Pp. xiv + 333; illustrated. 60s.) London: McGraw-Hill. 1957.

The author claims for the book that (i) it is a guide to industry on causes and control of hearing loss from exposure to intense noise; and (ii) all phases of industrial deafness have been covered for the first time in one volume.

It is not intended for the acoustical expert, but rather for a wide variety of specialists, such as otologists, compensation lawyers, industrial executives, and physicians, engineers, and nurses. Indeed, the net is very widely drawn.

The writer is very well qualified to attempt such a task, having spent years in research and clinical study of the subject, but in order to make the book as comprehensive as possible, he has invited several specialists to provide certain chapters so that the reader may have the benefit of the most authoritative information available.

The text is divided into three main parts, the first dealing with general considerations, the second with noise measurement, and the third with hearing testing.

Part I contains six chapters, and is intended to provide an overall perspective of the various problems relating to noise and deafness.

Chapter I covers the elementary physics of sound. Sound is defined, and sound waves, together with their characteristics, are described. Its measurement is also discussed in general terms. The explanations are simple, clear, and adequate.

In Chapter II there follows a much simplified description of the anatomy and physiology of the ear.

Chapter III opens with a general definition of deafness, followed by a description of certain varying causes such as blockage of the auditory canal, perforation in the eardrum, and infections. Varying types of deafness—conductive, perceptive, and functional—are next defined, and the common causes are again briefly discussed. It might have been preferable to have followed the definition of deafness immediately by a description of the varying types and their causes.

In the paragraph, under the heading of "Presbycusis", one is suddenly confronted with the mention of various frequencies without any previous explanation. It can well be imagined that this could be a cause of embarrassment to industrial executives and safety engineers. It is also considered that the audiometric curves, the first of which depicts a case of congenital perceptive deafness, are out of place in the context. It is difficult to believe that they would be understood by a reader being introduced to them for the first time.

Chapters IV, V, and VI, which complete Part I, are concerned respectively with the effects of noise on human behaviour, certain medico-legal aspects of industrial deafness, and conservation of hearing in industry. The first is dealt with far too briefly and inconclusively, the second is mainly of interest in an American setting, bearing no relationship to the legal position in Britain. The last chapter of Part I is supposedly dealing with the basic problems involved in developing a conservation of hearing programme. This is not so.

Part II, consisting of six further chapters, is somewhat more technical, being intended chiefly for safety engineers, hygienists, and technicians concerned with noise measurements. The first two chapters deal respectively with the principles and use of the appropriate equipment for measuring noise. The various types of noise most commonly encountered in industry are separated and described very briefly under four groups. The chapter ends with a method for recording and analysing the data, which should be satisfactory in practice.

The next chapter deals with damage-risk criteria relating noise to deafness, and sums up the present situation very fairly. Your reviewer, however, disagrees with the following passage:

> "The damage-risk concept necessarily introduces several important intrinsic questions. For instance 'what percentage of employees do we want to protect from deafness?' and 'How much hearing damage is permissible?' . . . We must, therefore, decide in each individual industry just how much hearing loss may be considered permissible in how many employees before we can actually establish rigid standards for hearing damage due to noise."

The sentiment expressed is entirely foreign to informed British thought. It is, therefore, somewhat of a relief to turn to the next chapter which gives skilful directions on how to choose and use ear protectors.

The last two chapters are headed "Principles of Noise Abatement" and "Audiometric Test Rooms" respectively. They are written by two of the chief collaborators. Both are excellent and not too technical.

Part III is devoted to all aspects of the testing of hearing, and is intended to serve as a guide and reference manual for those so engaged in industry. The first chapter deals with the measurement of hearing loss, and the second with audiometry, and are individually the most valuable in the book for the average reader. They are recommended most strongly to those who have already initiated their own programme, and are a necessity for all proposing to do so, as the directions for performing reliable and valid hearing tests are presented in a simple, step-by-step, practical manner.

The next chapter discusses ear examinations and histories, and is intended primarily for the industrial physician and otologist.

The succeeding chapters show how auditory fatigue, presbycusis, and malingering are three of the chief of many pitfalls in routine audiometry that may result in inaccurate interpretation of the results obtained.

The chapter following deals with the handicapping effects of deafness. The greater part of its subject matter, such as the psychological effects of hearing loss, individual reaction to deafness, effect of deafness on speech, and evaluating effects of deafness, can have very little appeal to the majority for whom the book is intended. The same criticism applies to the next chapter which discusses certain aspects of the interpretation of hearing tests.

In the last and final chapter the roles of the industrial physician and otologist are presented in detail. Paragraphs are devoted to the estimation of potential noise hazard; responsibility for the performance of noise and hearing surveys, and their evaluation; the timing for the removal of an employee from a noisy job because of hearing loss; and responsibility for supervising the distribution of ear protectors.

The list of references is brief but well chosen. The index is excellent.

In spite of the many criticisms offered, the book as a whole is well worth reading and studying in detail.

H. D. PAVIERE

Precancerogenesi e Tumori Professionali (Malattie professionali-Prevenzioni-Diagnosi e terapia precoci), Vol. 11. By Giorgio Alberto Chiurco. (Pp. xvi + 1268; illustrated. Lire 10,500.-.). Rome: Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro (Edizioni I.N.A.I.L.). 1956.

The late Sir Ernest Kennaway once expressed the opinion to your reviewer that the most profitable approach to the problem of human cancer lay in the study of man rather than of animals. Coming from a man who had so greatly advanced the subject of experimental cancer, this was indeed a revelation.

Although the experimental approach is still used to no less extent, there is an undoubted drive nowadays towards the study of the endogenous and exogenous factors but no real success can be attained in the study of cancer in man unless full data are made available. The difficulties are, of course, manifold but in no sense insuperable. Compulsory notification of all cancer cases during life with as much detail as can be obtained is a *sine qua non*. The important information relates to the lifetime of the patient and its collection will most usefully follow carefully designed notification form. Voluntary notification schemes in Britain in the last 30 years may have had a measure of success but ultimately the method must be compulsory.

In the volume under review it is quite obvious that Chiurco, who is a senior surgeon, is a protagonist of the statistical approach to human pre-cancer, cancer, and industrial cancer. In the 1,200 pages of text and many hundreds of world references as well as coloured charts of the propagandist type, large numbers of case histories and radiographs of pulmonary tumours, national and world statistics of cancer incidences in different organs, the author has contrived (with some collaboration) to gather together a great deal of information. Thus, to the question of how many people die of cancer in the world annually he gives del Vecchio's (1956) figures of 1·65 millions to 3·25 millions. If we take Tizzano's (1951) estimate of world population at some 2,400 millions, the crude mortality rate would appear to be some 700 to 1,400 per million. Del Vecchio's estimate of the total number of cancer cases per year is based on the belief that every cancer death is an index of two to three cases of cancer, so the number of cases would be between 3·3 million and 9·75 million in any one year, which at the upper limit would mean four cancers per 1,000 people on earth. This guess is probably not far from the truth.

The estimated mortality from cancer in the following continents, based on the sources of more reliable statistics in 1952, is as follows:

Continent	Approximate Cancer Mortality per 100,000		Probable No. of Cases on 3:1 Theory in 1952*
	1924	1952	
North America, Canada, U.S.A., Salvador	65	145	400–500
Europe	75	175	500–600
Asia, Ceylon, Israel, Japan	55	80	200–300
Oceania, Australia, New Zealand	75	160	400–500

*Added by reviewer.

Chiurco stresses L'Eltore's division of the world into four zones for comparing cancer mortality and other

	Zone 1 Mainly Industrial (Canada, U.S.A., Britain, France, Germany, Low Countries, and Scandinavia)	Zone 2 Agricultural (Central America, South America)	Zone 3 Agricultural with Little Mechanization (East of line joining North Cape to Cape of Good Hope)	Zone 4 Agricultural (Australia and New Zealand)
Infant mortality per 1,000 live births	<60	>60 + +	>60 + +	<25
General mortality per 1,000	About 10	>10	>10	<10
Exogenous causes of mortality	Low	High	High	Low
Endogenous causes of mortality	High	Low	Low	High
T.B. mortality per 1,000	<0·5	0·5–2·0	>2·0	<0·5
Cardiac mortality	High	Moderate	Moderate	High
Tumour mortality per 1,000	>1	<1	<1	>1
Food (Cal./day)	>2,900	1,900–2,900 (Argentine 3,000)	1,900–2,900	>3,000
Transport and communication	Intense	Sparse	Very poor	Moderate
Income	High	Low	Low	Medium
Iliteracy level	Low	High	High	Moderate

data, and it is perhaps worth while recalling from his table some of the suggestive general facts already agreed upon or worth pursuing further.

It is clear in general terms that a price must be paid for the advantages of high industrialization, high incomes and education, transport facilities, high efficiency of public health, and low general mortality. That price appears to be a high cardiac mortality and a high cancer rate.

Almost half this large volume is devoted to cancer of the respiratory tract, and the author has gone to great lengths to present data from most countries on the great increase in lung cancer, absolutely and relative to total cancer incidence, the much greater incidence in men than in women, the enormous increase in known and possible lung irritants resulting from transport and industrialization, and the relation to tobacco. He also gives the terrifying estimates of Coruzzi that (in round numbers) some 50 million people use cocaine, 100 million betel, 300 million hashish, 400 million opium, and about 800 million tobacco—all as addictions. The tobacco story is told with a certain ferocity but the author has not lost sight of the possibilities of additional exogenous factors in the environment, and, in the matter of urban conditions, conforms to the studies of Stocks in Britain and the very recent reports from Cincinnatti by Miller *et al.* (syncarcinogenesis and co-carcinogenesis). The author believes (p. 610) that there are in the body, otherwise in physical, hormonal, etc. equilibrium, a very small number of latent cancer cells which can erupt into activity from a factor X which may be endogenous or exogenous in origin.

In a 50-page discussion of occupational bladder tumours, the author presents a rather mixed-up story and insists still in attributing the condition to amino-nitro derivatives, in spite of absolutely no evidence that the nitro group has any place in the aetiology. The statement is also made that β-naphthylamine and benzidine and their homologues are the most powerful bladder carcinogens. This is not so.

It would, we think, have been unjust to deal summarily with this book, as indeed, has been done by at least one American reviewer, Chiurco's volume strikes one rather as the work of a teacher who has included too much and repeated too much, but has certainly given the reader much to think about. As is so often the case in Italian textbooks it is frequently an exasperating task to find text references in the bibliography.

M. W. GOLDBLATT

Entretiens de Physio-Pathologie Respiratoire, 2ième série. Reprinted from *Revue Médicale de Nancy*, Vol. **7,** p. 256. 1957.

This is the proceedings of the second of a series of conferences arranged twice a year by the Faculty of Medicine at Nancy with support from the High Authority of the European Coal and Steel Community.

The conference was devoted to three aspects of respiratory physiology relevant to the study of chronic lung disease: first, alveolar ventilation and gas exchange at rest; second, ventilation during test exercise; and third, the effects of oxygen breathing at rest and on exercise.

Each session was nicely balanced with papers describing the normal responses preceding others on the corresponding change in disease. They were followed by discussion.

In all there were 20 contributions of fairly even quality, eight from Nancy and the rest equally divided between Paris, the Low Countries, and Professor Fleisch's department at Lausanne, Switzerland. These and other countries on the Continent were represented in the discussions which were critical and well-informed and must have been a most valuable part of the proceedings.

The first session began with methods for estimating arterial carbon dioxide tension needed in the calculation of the resting alveolar ventilation. This is of value in assessing the degree of respiratory compensation in patients with an elevated arterial PCO_2 due to respiratory insufficiency. Such subjects often have a one second forced expiratory volume of less than 1·2 litres.

The session ended on the subject of arterial hypoxaemia in iron workers with pneumoconiosis. The suggestion is made that much of this is due to "venous admixture" or dilution of fully oxygenated blood with what is effectively venous blood from alveoli which are perfused with blood but poorly ventilated with air. More recent work points in the same direction (*e.g.*, H. L. Motley, 1958, *Fed. Proc.*, **17,** 114). However, there are a number of complicating factors, some of them raised in the discussion, which must be considered in relation to this interpretation and it is to be hoped that the subject will be considered again later this year at the next conference in the series.

The second session was concerned with ventilation during exercise. For a given level of exercise the ventilation is higher with advancing age, lack of exercise, and simple and complicated pneumoconiosis (P.M.F.) than it is in young normal subjects. In subjects with P.M.F. all these factors tend to operate together.

The third session was on reactions secondary to inhalation of oxygen in concentration greater than 21%. A number of useful points are made but none more pertinent than this one with which Professor Sadoul opened the discussion which followed:

> "Ni la saturation d'oxygène, ni le taux de CO_2, ni l'insuffisance ventilatoire évaluée par la spirographie, ni l'augmentation du volume résiduel ne semblent en corrélation étroite avec l'abaissement de la ventilation observée lors de l'hyperoxie."

The conference was clearly a success. To one physiologist reared in the Anglo-Saxon tradition it is especially interesting as indicating a trend away from spirometry and oximetry which have dominated respiratory physiology on the Continent over the past decade. However, we have not yet reached unanimity—witness the different versions of the alveolar air equation on pages 76 and 81, and it is a pity that the editors did not secure a consistent terminology amongst their contributors. The papers themselves are eminently readable and are provided with French, English, and German summaries. One misprint—75% instead of 64% in the English summary on p. 85—is a trap for the unwary. The proceedings make a useful contribution to the applied physiology of chronic lung disease.

J. E. COTES

Productivity and Social Organization: The Ahmedabad Experiment. By A. K. Rice. (Pp. xiii + 298. 35*s*.) London: Tavistock Publications. 1958.

For some years now there has been a steady flow of literature from the staff of the Tavistock Institute of Human Relations concerned with the sociology or social psychology of industry. Unfortunately, much of it has been very difficult to read or digest because the language used has tended to obstruct rather than facilitate the exchange of ideas. Mr. Rice's book goes a long way to make amends.

The book describes three experiments carried out in mills of the Ahmedabad Manufacturing and Calico Printing Company Ltd. Two of the experiments may be regarded as fairly classical studies of the reorganization of groups of operatives engaged in industrial processes, *viz.*, automatic and non-automatic weaving. The third is concerned with the reorganization of management. Before the experiments are described we are given a straightforward and concise account of the theoretical background that is deemed to be important in any changing industrial community. Even those who cannot spare the time to read the details of the experiments should read those sections (part II) which set out these theoretical considerations. It is argued that overall efficiency requires not only the technologically appropriate equipment but also a sociologically satisfying works organization. The gains that may be expected to flow from technical progress may well be nullified if they produce changes that conflict with the social needs of the worker. Even organizational structures which have been long established may well be inappropriate to the workers' psychological needs. Any investigation, it is argued, must first decide what these sociological needs are and how they are to be met. The culture of different societies will influence differently the conscious and unconscious needs of the industrial worker in his work environment. It is necessary therefore that this cultural background should first be examined. Where workers are working in groups, to be socially satisfying the group and its tasks must fulfil certain conditions, for example, conditions of size, of task organization, and of the individual roles of the members in the group. The role of each individual should not extend beyond that of the group as a whole. Having set out these and other principles the course of the experiments is described.

In the first place, a careful study and job analysis was made of the existing organization, the pattern thus revealed was then compared and contrasted with the theoretical ideal. The discrepancies are pointed out together with their theoretical and practical consequences. This is followed by a description of the course of events that took place as changes were made together with comment on the theoretical implications.

In neither of the weaving experiments was success achieved without local and national difficulties. For example, after the non-automatic weaving experiment had been running for approximately four months a national campaign against "rationalization" flared up and made the position of the workers in this shed very difficult.

In the automatic weaving shed

> "the first spontaneous acceptance of the new system and the subsequent determination to make it work were due primarily to the workers' intuitive acceptance of it as one which would provide them with the security and protection of small group membership which they had lost by leaving their villages and their families to enter industry. At the same time, the new system allowed them to perform their primary task effectively and thus provided them with an important source of satisfaction."

In the non-automatic shed

> "the acceptance of the new system and the determination to make it work were due to its providing more opportunities for effective task performance and for the building of stable and secure small work-groups relationships than those existing in the conventional system with which the traditional norms of performance and wages were associated."

The considerable changes that took place had their repercussions on the structure of management and the creation of new managing systems is described. The informal and personal management of the past had to give way to a new system of increased specialist knowledge and greater delegation to executive managers. Once more the approach followed well-accepted patterns.

> "The first task was to get a picture of the existing organization, of the reasons for its development, and of how it worked. Thereafter the overall socio-technical system of the mills was analysed and appropriate managing systems evolved, discussed, modified and finally established and manned."

In the final section of the book, "Social and Technical Change", the original concepts and assumptions are re-examined and discussed. Although the book is primarily an account of a discreet study in an Indian textile mill it is clear that this serves to illustrate much wider concepts and throw light on more universal problems. India itself is going through its own particular version of our western industrial and social revolution of the last century and a half. The problems which confront India may, it is argued, be more effectively tackled if attention is paid to the implications of social change as it affects different groups—management and worker—caste and caste—village and factory. New groupings will have to give satisfactions to replace those of the former grouping. Developing machine technology requires a works organization not only appropriate to the scientific and technological demands but also appropriate to the changing psychological needs of those who are involved in it. The satisfactions which formerly accrued to a man through what he did must be replaced by satisfaction through what his machine does. The need to recognize that technical change has its impact on social organization is important both in India, where industrialization is replacing craft and village industry, and in the west where automation is having its impact on the operator-machine relationships. HARRY G. MAULE

Ageing on the Factory Floor. By F. Le Gros Clark. Published by The Nuffield Foundation, London.

This is essentially the report of a study of ageing within the conditions of modern industry—in this case the production of domestic furniture—and some com-

ments and conclusions on the findings. At a time when the percentage of those alive over pensionable age has enormously increased and when the numbers are still rising, any attempt to study conditions in industry which affect the age of retirement is welcome. The writer wisely emphasizes that "it is not scientifically safe to generalize about ageing men from one set of working conditions to another" but obviously certain principles must hold in all working conditions, and these have been well brought out in this study.

First, the worker's overall initial training must clearly affect, when he becomes an older worker, his ability to move from one section of an industry to another. Those workers who have had an all-round training will more easily be transferable to work which may be skilled but physically lighter than those whose early training was in one small section only. Often in industry the maintenance of an older worker depends upon his ability to move—and this is especially so when he cannot for medical reasons remain in his previous position.

Secondly, the introduction of new machinery which diminishes the labour force must react on the employment of the older worker, but progress cannot in the terms of national economy be held back and these conditions must be studied.

Thirdly, the author refers to the attitude of the firm towards the continued employment of its older employees, which is probably the most important factor of all. Inherent in this attitude is the firm's choice of shop supervisors and foremen, for the breakdown of operations and the administration of transfers depends upon these key men for smooth running and coordinated overall timing in production. Without their sympathetic understanding in this approach the whole system of transfers and concessions to older workers would be impossible.

Those interested in the problems connected with the employment of older workers will find this study interesting and the arguments stimulating. It is to be hoped that this survey may lead to additional studies in other spheres of work as research into the subject of employment of older workers and allied problems is much needed at the present time.

MARJORY WARREN

First Aid and Early Treatment of Burns in the Royal Air Force. Air Ministry Pamphlet 168, 2nd ed. (Pp. 70; 14 figures. 3*s*.). Issued by the Air Ministry (D.G.M.S.). London: H.M. Stationery Office. 1956.

Many of the lessons learned in war are forgotten in the peace which follows. It is encouraging to see that this pamphlet published by the Air Ministry places on record the vast experience and latest thought gained in treating severely burned airmen by the R.A.F. Medical Service.

Ignorance and careless handling in the early stages are held responsible for some poor results in burned patients. With this in mind the book is divided into four sections:

Part I deals with protection from burns, enumerating well-known principles. Later chapters deal with first aid in a logical manner, emphasis being laid on preserving life, preventing extension of the injury, and the securing of medical help.

Part II deals with the treatment of shock and the early surgical procedures in cleansing and grafting of burns, including treatment of the type often carried out in medical departments in industry.

Part III is written for surgeons not specially trained in the treatment of burns and describes the surgical procedures which would be carried out in hospital. It includes some of the early plastic procedures involved in reconstruction and also an account of complications such as toxaemia, anaemia, and infection.

Part IV poses the problem of treating large numbers of burns such as might occur in thermo-nuclear air attacks.

This very readable and instructive little book should be of great interest and value to doctors, nurses, and first aid workers in industry, as well as to all those in the hospital service who have to treat burns. General practitioners may have little call on their services to deal with any but minor burns. This book would certainly bring them up to date if such a catastrophe should occur.

R. A. TREVETHICK

Microdiffusion Analysis and Volumetric Error, 4th ed. By Edward J. Conway. (Pp. xviii + 465; 79 figures. 42*s*.). London: Crosby Lockwood. 1957.

Professor Conway's valuable textbook describes in minute detail the principles of microdiffusion analysis and its application to the determination of a large variety of substances. The technique is particularly useful for the study of clinical and biochemical problems. A most useful section is the 91 pages devoted to the consideration of the errors of volumetric titration; this is of value to all analysts.

This new edition illustrates recently developed microdiffusion units and also describes the use of a vibrating table, the use of which considerably decreases the reaction time. A carefully designed distillation unit is also described which allows the use of the technique at elevated temperatures. The diffusion technique can now be used as a routine laboratory procedure for the determination of blood ammonium; recent developments in methods are discussed. A new catalytic Kjeldahl method for nitrogen estimation is given. Among the substances which may be determined by the new methods are glutamine, monamine oxidase, histamine, cyanide, sulphide, phenols, methanol, isopropyl, alcohol, azide, methane, formaldehydogenic steroids, glycine, and acetaldehyde. Improved methods for the estimation of lactic acid in blood, of carbon monoxide, and halogens are also included.

Every analyst dealing with small quantities of material should be well acquainted with the microdiffusion principle and to them Professor Conway's book is virtually essential.

B. T. COMMINS

Books Received

(Review in a later issue is not precluded by notice here of books received.)

Pre-Employment Disability Evaluation. By William A. Kellogg. (Pp. xv + 155. 80*s*.) Oxford: Blackwell Scientific Publications; Springfield, Illinois: Charles C. Thomas. 1957.

The Handicapped and Their Rehabilitation. Edited by Harry A. Pattison; Introduction by Major General Melvin J. Maas. (Pp. xxxii + 944. £5 12*s.* 6*d.*) Oxford: Blackwell Scientific Publications; Springfield, Illinois: Charles C. Thomas. 1957.

Cardiovascular Rehabilitation. By Paul Dudley White, Howard A. Rusk, Bryan Williams, and Philip R. Lee. (Pp. vii + 155. 50*s.* 6*d.*) London, New York, Toronto: McGraw-Hill. 1957.

Notice to Contributors: Abstracts

Starting with Volume 16, No. 1 of which will be published in January, 1959, it is proposed to publish an abstract before each paper. Contributors are therefore requested to submit an abstract for publication with their papers. The abstract will take the place of the summary which was formerly published at the end of each paper. If the author wishes, however, a brief summary of results or a section headed " Summary and Conclusions " may be given at the end of the paper, but this section should not repeat the contents of the abstract. Examples of journals which publish abstracts are the *Journal of Applied Physiology* and *The Analyst*.

The abstract should be concisely written in good—not telegraphic—English. The paragraphs should not be numbered. Its purpose is to attract the reader's attention to the paper, to which it should lead on naturally; by writing his own abstract, which it is hoped abstracting journals will use, the author will be able to ensure that his views are adequately set forth in balanced proportion.

For the guidance of contributors, the abstract should always include (1) a statement of the purpose for which the investigation or review was undertaken; (2) the selection of the material used or measured; (3) the method(s), procedure(s), or treatment employed; (4) the results obtained; and (5) the author's conclusions or explanations.

An essential attribute of an abstract is brevity, which must be achieved by selection rather than compression and must avoid any risk of ambiguity. Clarity and good style are as important in an abstract as in any other form of scientific writing. The introduction of jargon, use of unexplained abbreviations, and failure to state units of measurement in precise terms should be avoided.

There is no standard length for an abstract, but it will usually be found that three to four hundred words are sufficient.

The British Occupational Hygiene Society

The British Occupational Hygiene Society is arranging a conference on " Vision, Lighting, and Colour " on Tuesday and Wednesday, November 11 and 12, 1958, at the London School of Hygiene.

On the first day papers will be presented on:—

1. " The Physiology of the Visual System and Colour Vision " by Professor W. D. Wright of Imperial College.

2. " The Subjective Aspects of Comfort and Discomfort in Lighting " and " The Problem of Visual Fatigue and its Measurement " by Dr. R. G. Hopkinson and Mr. J. B. Collins of the Building Research Station.

3. " The Rating of Visual Tasks " by Mr. H. G. Weston, the Medical Research Council.

4. " Modern Methods of Artificial Lighting " by Mr. M. W. Peirce of the General Electric Company Limited.

On the morning of the second day there will be a paper entitled " Colour in Factory Buildings " by Mr. L. V. Jones of the Colour Advisory Department of I.C.I., and in the afternoon a visit will be paid to the factory of the Paints Division, I.C.I., at Slough, Bucks.

The conference is open to non-members of the Society on payment of a registration fee of one guinea. Those who wish to attend should write to the Honorary Scientific Secretary, Dr. D. Turner, The Associated Ethyl Company Limited, Ellesmere Port, Cheshire.

Occupational Health Prize

The **Occupational Health Prize** was established by the British Medical Association for the purpose of encouraging interest and research in the field of occupational health. The Council of the British Medical Association is prepared to consider the award of this prize, which consists of a certificate and £50, in the year 1959.

Any member of the Association who is engaged in the practice of occupational health, either whole-time or part-time, is eligible to compete for the prize. Candidates may select their own subject.

Entries should be submitted in a form suitable for publication and must include personal observations and experiences collected by the candidates in the course of their work. If no entry is of sufficient merit no award will be made. Candidates should confine their attention to their own observations rather than to comments on previously published work on the subject, though reference to current literature should not be omitted when it bears directly on their results, their interpretations, and their conclusions.

Entries must be sent to the Secretary, British Medical Association, B.M.A. House, Tavistock Square, London, W.C.1, not later than January 31, 1959.

No study or essay that has been published in the medical press or elsewhere will be considered eligible for the prize, and a contribution offered in one year cannot be accepted in any subsequent year unless it includes evidence of further work. A previous prize-winner is not precluded from entering.

If any question arises in reference to the eligibility of the candidate or the admissibility of his or her essay, the decision of the Council on any such point shall be final.

Preliminary notice of entry for this competition is required on a form of application to be obtained from the Secretary.

Each entry must be typewritten or printed on one side of the paper only, and accompanied by a note of the candidate's name and address.

The Council anticipates that contributions should be between 3,000 and 10,000 words, although no definite limits are laid down.

Enquiries relative to the prize should be addressed to the Secretary, British Medical Association House, Tavistock Square, London, W.C.1.

INDEX
PAGES
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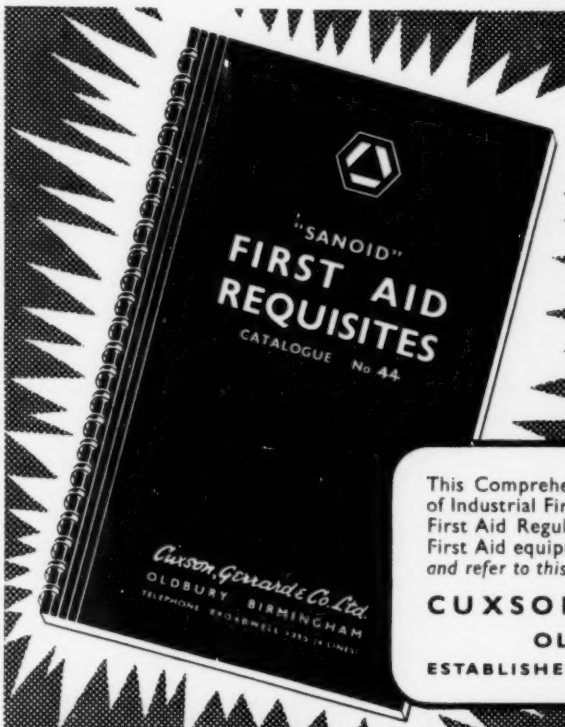

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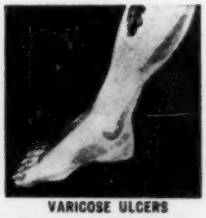
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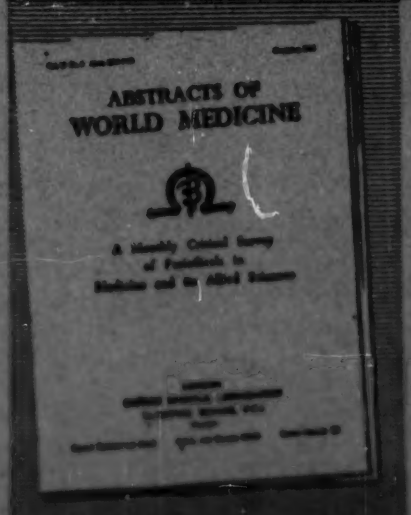

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